REPORT 61

SWEEP

SOIL AND WATER
ENVIRONMENTAL
ENHANCEMENT PROGRAM

Rec'd at Research Station
FEB 1 1993
Harrow, Ontario

PAMPA

PROGRAMME D'AMELIORATION
DU MILIEU PEDOLOGIQUE
ET AQUATIQUE

Canada

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

100-05271/

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

FINAL REPORT OF THE TECHNOLOGY EVALUATION AND DEVELOPMENT (TED) SUB-PROGRAM OF THE SOIL AND WATER ENVIRONMENTAL ENHANCEMENT PROGRAM (SWEEP)

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Disclaimer: The views contained herein do not necessarily reflect the views of the Government of Canada or the SWEEP Management Committee.

ACKNOWLEDGEMENTS

... There is always serendipity. Remember the Three Princes of Serendip who went out looking for treasure? They didn't find what they were looking for, but they kept finding the things just as valuable. That's serendipity and our business is full of it.

George Merck
Leading Pharmaceutical Manufacturer
TIME, Nov. 3, 1951

Throughout this report by the Technology Evaluation and Development subprogram, the acronym "TED" is used almost as a personal pronoun which sounds like "WE". A shorthand convenience, this device described a partnership linking a great many people who carried on this work. In this partnership were a small army of farmers who had input into planning, revising and evaluating projects; the scientists, graduate students and technicians from the Universities, especially the University of Guelph, who gave freely of their time, training and experience to researching a wide range of technical subjects in this program; the private sector consultants and their staff who ventured, on occasion, into uncharted areas of program but who never at anytime placed their interest ahead of that of the client; and TAP, that selected body of experts from the agricultural community who met regularly during six or more years to advise and assess the deliberations of the Soil and Water Environmental Enhancement Program (SWEEP) on behalf of the respondents to this joint federal/provincial initiative. Together, the partnership faced and solved problems which we the authors are pleased to present and discuss in this final SWEEP-TED report.

Others are acknowledged without whose help this subprogram would not have functioned. Among these are the federal employees from Agriculture Canada in the Agri-Food Development Branch, Guelph, the Research Branch, Harrow Research Station; representatives of the Ontario Ministry of Agriculture and Food, the Ministry of the Environment, Environment Canada and Conservation Authorities of the Ministry of Natural Resources in Ontario, who from time to time sat on the Working Committee. The advice and service of Supply and Services Canada in providing the mechanisms for tendering, contracting and executing contracts is especially appreciated.

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EXECUTIVE SUMMARY

In August of 1985, the Governments of Canada and the province of Ontario announced the beginning of a coordinated federal/provincial program to deal with soil conservation and water quality as part of the Canadian response to an international agreement with the United States to reduce phosphorus loads to Lake Erie. A Five Year Implementation Plan was developed which set out the program objectives of a 200 tonne annual reduction in P loads due to agriculture. This target was to be met by encouraging and assisting 8,000 farmers cropping 400,000 hectares of land to adopt appropriate conservation cropping practices. Allocating the 200 tonne objective over 400,000 ha meant that an average annual reduction of 0.5 kg of P per ha was required.

The Technology Evaluation and Development (TED) Subprogram of the Soil and Water Environmental Enhancement Program (SWEEP) ran from February of 1987 until September of 1992. This final report presents a summary of the subprogram.

The TED program was successful in responding to the research priorities identified during a detailed planning process. The planned research was implemented and completed on budget and on schedule making efficient use of a range of research capabilities throughout the province. The available research funds were equitably distributed between research institutions, such as the University of Guelph and the private sector. A number of productive joint ventures between research institutions, private sector contractors and active farmers were encouraged and supported. Regular review of the program progress with the Technical Advisory Panel resulted in modifications and research enhancements which improved the focus and overall achievement of the program objectives. Communication of research results and opportunity for input was provided to a wide range of interest through the use of Progress Summary Bulletins and research conferences.

The TED subprogram of SWEEP was conceived, developed and delivered as a cooperative venture between farmers, research scientists and administrative personnel. Any success which the TED subprogram achieved was due to the tremendous cooperation of individuals within these different groups.

Of the 53 research projects funded by TED, 21 (40%) were awarded in response to the formal Request for Proposal procedure, while 32 (60%) were awarded as a result of unsolicited proposals. Work conducted as a result of unsolicited proposals had to be justified by a demonstrated need for the knowledge which the work would provide.

The TED subprogram was given a mandate to focus on research conducted at the farm scale. Nearly 78% of all the research money spent during the TED subprogram was spent on projects which were conducted on viable commercial farms. In addition, an additional 5.5% of the research money was spent on studies which used a combination of farm and research station resources. Two hundred and thirty five farmers were directly contacted through the TED program. Of these 235 individuals, 148 were directly involved in some component of the TED research. One of the first projects awarded under TED was a survey of conservation practices being tested, revised and adopted by leading farmers in Ontario. This study was valuable to TED in refining the farmer position on research priorities and identifying a resource group of advisors and research cooperators.

In addition to supporting, strengthening and enlarging the network of farmer to farmer communication about conservation practices, the TED program assisted in the training and professional development of a number of technicians, researchers and research groups.

TED identified a need for tools which would assist farmers in reducing the risks associated with the transition from conventional to conservation farming. Means of providing these tools were explored to some extent at the TED Modelling Workshop held in November, 1988. An existing approach which showed the greatest promise was developed by ROBBERT ASSOCIATES, and derived from a five year program in Statistics Canada to develop a socio-economic resource framework. The promise shown

by the first phase of the project conducted under TED clearly indicates a potential for meeting the established guidelines outlined above.

RESEARCH

Farm Managment Systems

A high priority research topic identified in the early planning stages of TED was the management of farm-field variability. The project arose out of the identified need to better understand the challenges involved in managing farm fields with complex topography, soils and drainage patterns. The main conclusions were that large amounts of soil and associated phosphorus are being moved within fields with complex topography in southwestern Ontario.; and the amount of soil and phosphorus moved within a field does not necessarily relate to the amount of soil and sediment delivered to streams. Therefore the crop productivity impacts of soil movement in complex fields can be significantly greater than the environmental and water quality impacts.

A study was undertaken to investigate an alternative farm management system developed by a group of innovative farmers known as the Ontario Biological Aeration Tillage Association (OBATA). Over the three field seasons of the research, many of the OBATA treatments appeared to have little or no quantifiable agronomic benefits. Soil fertility, structure and compaction, and microbial biomass did not appear to differ between the OBATA and standard treatments. Rainfall simulation indicated that the practices did result in reduced soil and phosphorus losses whem compared to conventional practices. While the TED studies did not show the OBATA system to be agronomically superior to the standard management system, it may be a viable alternative to conventional agriculture, offering comparable yields and net returns, while reducing soil erosion and phosphorus losses. Since pasture and manure management are readily included in the OBATA system, it may appeal more to farmers with livestock than those who grow strictly cash crops.

Cropping Strategies

The TED studies explored a range of management and species alternatives for cover crops and developed the establishment and elimination methods required to successfully incorporate their use into a farm system. The success of a succeeding crop often appeared dependent on using some degree of tillage in the spring prior to planting to provide an optimal seed bed environment in the presence of crop residues. Pushing residue aside was also often successful. Cover crops appear to have great potential to contribute to the reduction in soil erosion from cropland as evidenced by the biomass and residue covers which could be achieved over winter.

What is less clear from the research, is the link between main or cover crop residues and yield reduction responses. The effects of residues on soil temperature and soil moisture revealed that reduced temperature under residues may delay development but did not necessarily reduce soybean and corn yields. The development of the nitrogen soil test would be a useful tool in the management of soil fertility with cover crops. Similarly, a screening test may be of help in choosing a corn hybrid that may be better able to emerge at cool temperatures.

Tillage Options

"Tillage Options" was identified as one of the research priorities for TED in the Background Paper, prepared by the Centre for Soil and Water Conservation, and by the participants of the initial planning workshop. Eleven tillage related research contracts were awarded during the TED program. Studies on subsoiling were included in the tillage options category as were development and testing of new planting or fertilizer application equipment for conservation tillage systems.

Several projects provided researchers and farmer cooperators with an opportunity to test promising new planting and tillage equipment under Ontario conditions. Minor modifications to existing technology were also tested such as the cutoff mold board plow which appears to be a viable first step for farmers towards conservation farming. Studies were conducted to assess the benefits of subsoiling on soil properties and subsequent crop yields. Overall, the TED studies did not come out in favour of subsoiling. It does not appear to be cost effective unless a severe compaction problem exists.

A contract resulted in the publication of a booklet by OMAF, entitled "Equipment Modifications and Practical Tips for Use." This publication contained photographs and descriptions of a wide range of modifications to moldboard plows, chisel plows, tandem disks, conservation seed drills, row crop planters and ridge-till systems.

Fertility Management

The confirmation that nutrient stratification exists in systems in which tillage does not mix or shallowly mixes fertilizer with the soil was expected. There is no indication that this would be of concern to farm management in terms of application rates and soil testing methods. The TED work indicated that increased phosphorus contribution from these fields is unlikely where conservation tillage acheives a concurrent reduction in sediment detachment.

Further, nitrogen losses from conventional, ridge tillage, and zero tillage corn in runoff and tile drainage were similar and there was no indication that conservation practices would lead to greater pollution of nitrogen in waters. A sod crop dramatically reduced nitrogen losses and nitrogen concentrations in runoff and tile waters relative to any of these corn systems, however, which would suggest that cover crops or intercrops may play a role in reducing nitrate leaching from soils.

The research which examined this possibility found that the cover crops of ryegrass, oilseed radish, and red clover, scavenged nitrogen initially but that soil nitrate levels were often as high or higher under the cover crops during the late fall and winter. The pattern of release of the nitrogen differed widely among the cover crops with some (oilseed radish) releasing too early to be largely available to a corn crop while others immobilized nitrogen to the extent of depressing corn growth early in the season in the absence of supplemental nitrogen. There seems considerable opportunity to understand the contribution of cover crops in nutrient cycling.

There was some evidence from this same study that the various cover crops are leached of their nutrients to varying degrees by rainfall. The question of the importance of residues in contributing to soluble P levels was raised.

The manure management studies in TED provided useful agronomic information and tested some interesting and environmentally viable systems for manure applications. The design, timeframe and budget of the manure studies did not allow for full evaluation of the environmental implications of the management. In some cases the manure was not incorporated, such as the applications to established forages and to winter wheat in the spring. These systems have the advantage of providing high ground covers of 50 to 100% which could be expected to minimize runoff and soil erosion.

Other management systems, such as manure applications following winter wheat harvest and soybeans, provide opportunities for manure incorporation. When incorporation is accomplished by tillage which does not involve full soil inversion by moldboard plowing, the main crop residue may provide sufficient cover to reduce soil erosion. Some tillage was shown to be required to maximize corn yields the following year in these studies.

Pest Control

Research carried out since 1987 under TED provided substantial evidence to reject the notion that reduced tillage systems lead to greater weed problems and higher herbicide dosages. At the beginning of the TED program a very strong concern was expressed by the most experienced conservation farmers that weed management and the availability of appropriate products was, or could become a serious problem. By the end of the TED study it seems safe to conclude that their concern is significantly reduced. A number of new mixes and rates of application using currently registered materials and usages which have proven to be extremely effective in controlling weeds at reasonable cost. An innovative farmer was able to demonstrate a 60% reduction in herbicide use through the integrated use of a herbicide banding and interrow cultivation. This reduction offers significant environmental and economic benefits, while at the same time appearing to have no adverse effect on weed pressures. The system was developed to the point where the inter-row cultivation was performed at the same time as nitrogen fertilization which meant no additional passes across the field. In effect, the secondary cultivation allowed the farmer to save 60% on his herbicide bill without substantially increasing the costs of his field operations.

No significant problems with either slugs or armyworms were reported, despite the fact that in many of the research plots, residue cover was in excess of 75%. However, the lack of slug problems may be attributed to the drier than normal conditions which generally prevailed during the three field seasons. No evidence that fusarium infections can be linked to the adoption of soil conservation practices was found.

Water Management

Attempts under TED to monitor the water quality impacts of water control structures were unsuccessful due to weather problems. Some empirical data are required to calibrate available models. Once these data are available modelling should prove to be a more reliable and cost effective method of monitoring these structures.

Some tillage and farm management practices, such as cultivation, mulch tillage, residue management and cover crops, have the potential to increase the rates of infiltration and percolation into cropped land. A portable device, the Guelph Pressure Infiltrometer (GPI), was developed and used to compare the infiltration rates from soils under conventional and conservation tillage systems. The GPI provided rapid measurements of a number of soil hydraulic properties and is a promising research tool for further work.

Rainfall simulations were conducted in a separate contract on a large number of TED research sites. Although differences in surface hydraulic properties were not specifically examined, the response of different treatments to the simulated rainfall did show relative differences in surface infiltration rates. The results from the simulations were highly variable, but generally in agreement with those from the GPI study.

At a monitored upland site, surface and tile flow from a fall moldboard plow tillage system and a no-till system were monitored and compared. Very little surface runoff occurred during the first 12 months of the monitoring period. It was concluded that the sandy loam soils at the site were not susceptible to surface runoff and erosion under either the no-till or fall plow systems. When rainfall simulations were conducted on a part of the field that had clay loam soils, both runoff volumes and soluble orthophosphate losses were greater from the no-till soils.

The results from a monitored lowland site indicate that conservation tillage is not sufficient to reduce phosphorus losses from cropland located on flat clay soils. Other measures may be necessary, such as optimizing phosphorus fertilizer use, or controlling the flow and re-using the tile drainage water (subsurface irrigation, creating wetlands, etc.), to keep the nutrients in the fields. The technology and options for accomplishing this were not investigated further.

Problem Understanding

Rated as a high priority was the examination of the nature, extent, and possible remedies to allelopathic and phytotoxic effects related to conservation farming and specific crop rotations. The specific compounds studied were volatile fatty acids (VFA's) which are by products of biological fermentation, and phenolic acids which are organic compounds initially leached from crop residues. Corn did not consistently exhibit a yield reduction response to the presence of crop residues on the soil surface and hence the observation of farmers related to phytotoxicity could not be reproduced in research trials in the field.

Studies were conducted to determine the extent of soil compaction on lowland clay soils in southern Ontario. Results indicated that around 50 to 70% of clay to clay loam soils in Lambton, Middlesex, Kent, Essex, and Elgin Counties have some degree of subsoil compaction. Twenty-five percent of these are considered to be severely compacted. Subsoiling of these lands was generally not beneficial to crop yields, and may be of use only on severely compacted soils.

As a progression from studies carried out in TED and Tillage 2000 examining variability of fields and effects of landscape positions on soil loss, research focused on shoulder slope erosion and the extent to which tillage operations move soil up and down slopes. This research is continuing beyond the TED term.

Summary

The report concludes with a discussion of the TED process and the Results of the research. Recommendations for the planning and management of future research programs are made. In addition specific topics for future research are suggested in the area of soil and water quality, farm management systems, soil fertility and nutrient management, crop residue management and tillage practices.

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1. INTRODUCTION

The Technology Evaluation and Development (TED) Subprogram of the Soil and Water Environmental Enhancement Program (SWEEP) ran from February of 1987 until September of 1992. This final report presents a summary of the subprogram. The following topics are addressed in this report:

- Background and objectives of SWEEP/TED;
- Institutional design;
- TED objectives and mandate;
- Systems approach used in TED;
- Results of the TED Research Program;
- Discussion and interpretation of results;
- Remaining research needs;
- Conclusions and recommendations.

Each of these topics is dealt with in more detail in separate TED reports. For a complete understanding of the TED Subprogram, reference should be made to the documentation listed in Appendix A.

The Statement of Work for the TED Subprogram was:

> *the Technology Evaluation and Development Subprogram will develop, adapt and evaluate cost-effective technologies and technologies systems that will lead to soil conservation and improved water quality. The benefits will be achieved by reducing the movement of soil, phosphorus and other chemicals from cropland to water systems. As such, the Subprogram will consider conservation tilling and planting and integrated pest management.*
>
> *The Subprogram is intended to develop and test technologies and technology systems which have a high probability of being successful on commercial farms. In general, testing of these technologies will occur on commercial farms in priority areas. The technologies or technology systems will be evaluated for their impact on both soil quality and the crop production and on economic benefits and costs.*

In January of 1987, Ecological Services for Planning Ltd. was awarded a contract to manage the TED research project on behalf of Agriculture Canada. The role of Ecological Services for Planning Ltd. was to assist the Scientific Authority for TED in the planning, day-to-day management and overall delivery of the program. A general direction with specific research priorities was set during the early stages of the program through extensive consultation with all parties responsible for the design, administration, delivery and ultimate use of the end products of the study. This consultation included several intensive planning workshops involving people with a stake in the outcome of TED. These stakeholders included farmers, government representatives, scientists, extension personnel and a wide range of private sector researchers who were candidates to conduct the work. This initial direction and set of research priorities was adhered to throughout the study. Periodic review of the program direction was conducted through workshops and conferences with the same groups on the conduct and use of the research program. Minor modifications and refinements to the project direction were made as a result of this consultation. This process of planning, consultation and refinement resulted in the research and conclusions discussed in this report.

In reading this report there are two very important points which should be kept in mind. First, TED was only one part of the larger SWEEP program. The results, conclusions and accomplishments discussed within this report are discussed from the perspective of the TED program. This is not to imply that the TED program was responsible for these achievements on its own. TED results are built upon, and interlinked with the results and efforts of all the other SWEEP components.

The second point to be considered while reading this report is that SWEEP and TED were government initiated programs which relied upon the willing participation and cooperation of large numbers of non-governmental people and institutions. This report will suggest that there have been major advances made in the understanding and application of conservation farming practices over the six-year life of the SWEEP program. That is not, however, meant to imply that these advances would not have occurred without the TED program. Prior to the initiation of TED there were dedicated individuals and groups and individuals promoting the use of farming conservation practices. These dedicated people would have made significant advances over the five years with or without the assistance of the TED subprogram. The people responsible for delivering the TED subprogram are honoured and proud to have been able to cooperate with these groups to assist in the advancement of the science and application of conservation farming practices.

The TED subprogram of SWEEP was conceived, developed and delivered as a cooperative venture between farmers, research scientists and administrative personnel. Any success which the TED subprogram achieved was due to the tremendous cooperation of individuals within these different groups.

2. THE SWEEP AND TED PROGRAMS

2.1 BACKGROUND TO THE SWEEP PROGRAM

Under the 1978 Great Lakes Water Quality Agreement, Canada and the United States agreed to protect the upper Great Lakes and, through a range of measures, to reduce phosphorus (P) loading to the lower Great Lakes. The measures to be used included decreased residential and industrial use of phosphates, improved sewage treatment facilities and the control of non-point sources. In October 1983, Canada and the United States agreed to further reduce P loading to Lake Erie by 2000 tonnes per year. While the United States was responsible for the reduction of 1700 tonnes of the P load, Canada was responsible for the remaining 300 tonne reduction by 1990.

In order to carry out their responsibility under the agreement, Canada planned to reduce the P loading from municipal and industrial sources by 100 tonnes, and to reduce the loading from agricultural cropland sources by 200 tonnes. Reduction of P from cropland was to be achieved by the improvement of soil management and conservation practices on farms in priority drainage areas.

In August of 1985, the federal and provincial ministers announced the beginnings of a coordinated federal/provincial program to deal with soil conservation and water quality issues in southwestern Ontario. This agreement, which was negotiated and signed in early 1986, represented the formal beginning to the Southwestern Ontario Soil and Water Environmental Enhancement Program.

The Soil and Water Environmental Enhancement Program (SWEEP), involved both agricultural and environmental ministries of the federal and provincial governments. The provincial and federal sectors had individual and joint responsibilities in the overall program which was stratified into subprograms as described in Section 2.4.

2.2 OBJECTIVES OF SWEEP

The Southwestern Ontario Soil and Water Environmental Enhancement Program (SWEEP) was developed to respond to existing and potential deterioration of soil and water resources. Its broad goals were:

- the reduction of annual phosphorus loading from non-point agricultural cropland uses to Lake Erie by 200 tonnes by the year 1990
- the increased productivity of the primary agricultural sector in Southwestern Ontario by reducing or arresting soil erosion and degradation.

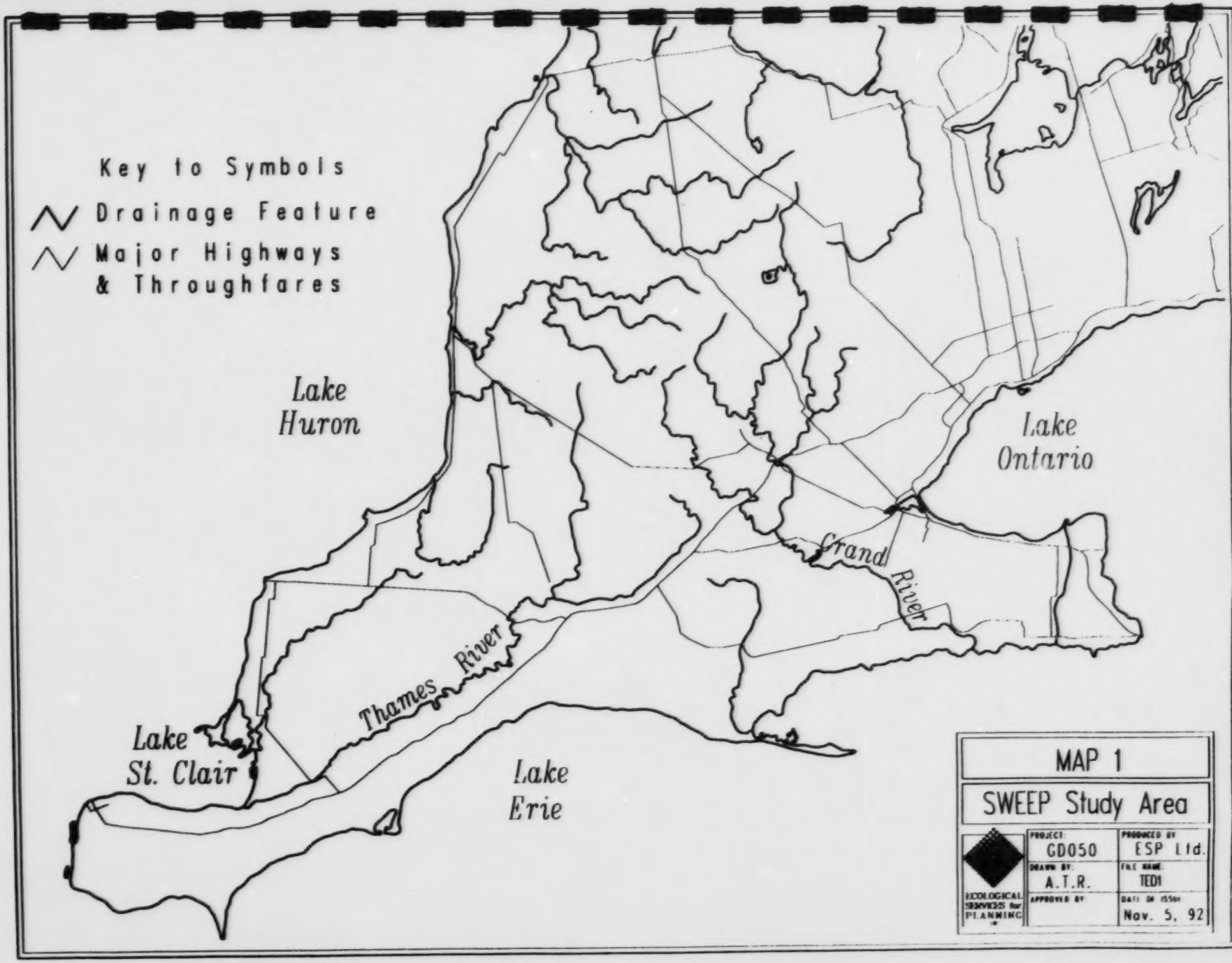
The study area for SWEEP was broadly defined as southwestern Ontario (Map 1). This includes the drainage basins for Lake Erie, Lake St. Clair , St. Clair River and the lower part of Lake Huron (the Ausable, Bayfield and Maitland Rivers). Conservation cropping in watersheds draining directly to Lake Erie (eg. Grand River) will have the most immediate impact on phosphorus loadings to Lake Erie. However, reductions in phosphorus loads to Lake St. Clair and lower Lake Huron will also contribute to long term phosphorus reduction in Lake Erie.

The Five Year Implementation Plan for SWEEP set out to achieve the program objectives of a 200 tonne annual reduction in P loads due to agriculture by encouraging and assisting 8,000 farmers cropping 400,000 hectares of land to adopt appropriate conservation cropping practices. Allocating the 200 tonne objective over 400,000 ha meant that an average annual reduction of 0.5 kg of P per ha was required.

2.3 INSTITUTIONAL DESIGN

SWEEP

The design of SWEEP was unique in Canada. Since the concerns which led to SWEEP were environmental, both agricultural and environmental agencies from the provincial and federal government were involved. In addition to both federal and provincial government agencies SWEEP involved non-governmental organizations such as universities and farmer organizations in the planning and implementation of the program. The third major sector of society involved in the program was private sector, for-profit business. The private sector was involved in the management, promotion and research undertaken in SWEEP from the earliest stages of the program. This private sector involvement was important in linking the environmental and production objectives and in providing effective links among the various participants. This broad base of program participants hopefully reduced the potential for biases and limits due to "territorial" or jurisdictional concerns which might have occurred had government agencies managed or conducted the research in traditional fashion.


Key to Symbols
Drainage Feature
Major Highways & Throughfares
Lake Huron
Lake Ontario
Grand River
Thames River
Lake St. Clair
Lake Erie
MAP 1
SWEEP Study Area
ECOLOGICAL SERVICES for PLANNING
PROJECT: GD050
PRODUCED BY: ESP Ltd.
DRAWN BY: A.T.R.
FILE NAME: TED1
APPROVED BY:
DATE OF ISSUE: Nov. 5, 92

TED

TED, as a subprogram of SWEEP, shared the same institutional design and the same participants - farmers, government representatives, scientists, extension personnel, and a range of private sector researchers. The practical, farm level, orientation of TED encouraged the development of a research program which involved farmers in the planning and conduct of research and in the interpretation of results. In this sense, TED was an experiment in developing a closer relationship between research and practice; in developing a program in which both the development and application of knowledge were viewed as integral parts of the technology transfer system. The regular involvement of farmers in planning, conducting and interpreting of research provided a constant reminder that farming is both a science and an art. All the science and conservation techniques developed in laboratories and research stations will have no impact on the goals of SWEEP until an individual farmer practices and applies the technologies in the context of a complicated system with all the soil, biological, climatic and human variables that make farming such a constant and changing challenge.

2.4 SWEEP SUBPROGRAMS

SWEEP included several integrated subprograms to be administered by Agriculture Canada, on behalf of the federal government, over the five year implementation Period. The subprograms included:

- **Technology Evaluation and Development (TED)** - testing of new or modified technologies in the area of conservation cropping, tillage, and land management.
- **Pilot Demonstration Watershed (PDW)** - a large scale implementation program of tillage plans at a watershed level, to test comprehensive implementation, farmer acceptance, water quality response, and soil and crop impacts.
- **Socio-Economic Evaluation** - to test economic feasibility and farm level acceptance.
- **Communication** - to promote technology transfer and public awareness.
- **Farm Level Economic Analysis (FLEA)** - to determine the cost effectiveness of technologies.

The provincial responsibility within SWEEP focused on the extension of technology to the farming community through demonstration, incentives and technical support. The evaluation of the environmental effects of the program was a joint provincial-federal responsibility. All of the components of SWEEP are depicted in Figure 1.

Administrators of the subprograms were assisted by a Technical Advisory Panel (TAP) which provided advice and a critical review of program components. The membership of TAP was carefully selected to reflect the diversity of the participants within the SWEEP program. A significant number of the members were active, full-time farmers who were dedicated to the application of conservation farming techniques. This group provided practical orientation for the panel. The panel also consisted of agricultural extension personnel, research scientists and government program administrators. This diverse makeup of the panel allowed it to provide significant input to the design and management of the TED subprogram. The practical knowledge of the farmers and the research experience of the scientists also provided significant input to the interpretation of the results of various research projects. Each subprogram was responsible to a scientific authority (SA). They were closely inter-related and required integration and collaboration on behalf of the various component participants. This need for integration led to the design of the program which included coordination and integration at three levels: TAP for technical input and practical concerns; a Working Committee responsible for day-to-day coordination; and a Management Committee responsible for inter-jurisdictional coordination.

2.5 TED MANDATE

The stated purpose of the Technology Evaluation and Development (TED) subprogram was to develop, adapt, and evaluate cost effective technologies that would lead to soil conservation and improved water quality. These technologies were to have a high probability of being successful on commercial farms. Field scale tests were, therefore, generally conducted on commercial farms in priority areas, with the direct cooperation and involvement of farm operators. The technologies being tested were evaluated for their impact on erosion, water quality and crop production.

Economic benefits and costs were to be evaluated by the Farm Level Economic Analysis subprogram of SWEEP.

During the delivery of the TED Subprogram, the mandate and focus evolved in response to the input of participants and cooperators. The detailed expectations of the program were refined, and the relative importance of achieving objectives was continuously reassessed. This evolution of program focus and objectives did not result in deviation from the original broad goals of the TED program. However, it did result in a better understanding and

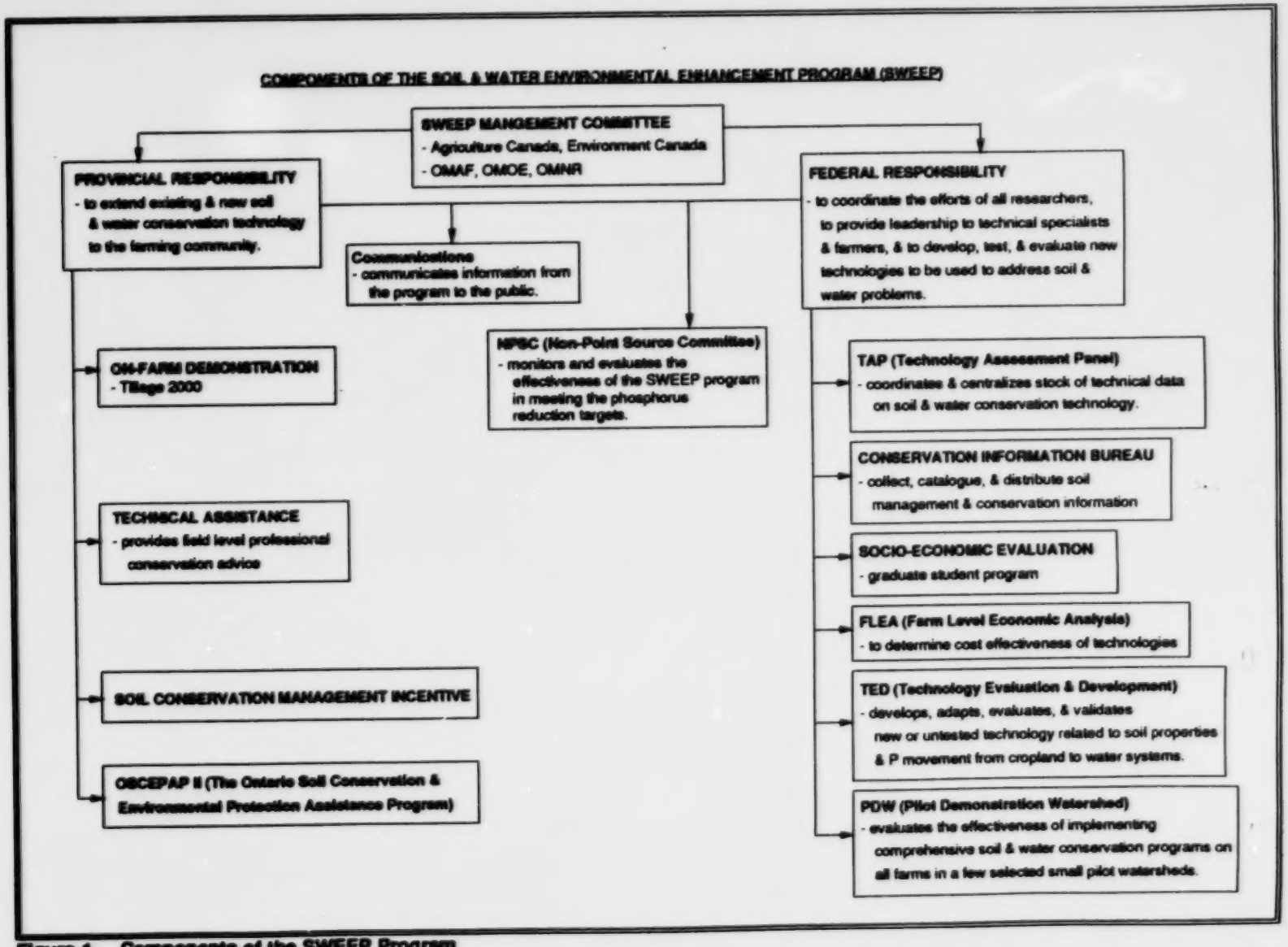

COMPONENTS OF THE SOIL & WATER ENVIRONMENTAL ENHANCEMENT PROGRAM (SWEEP)
SWEEP MANAGEMENT COMMITTEE
- Agriculture Canada, Environment Canada
- OMAF, OMOE, OMNR
PROVINCIAL RESPONSIBILITY
- to extend existing & new soil & water conservation technology to the farming community.
FEDERAL RESPONSIBILITY
- to coordinate the efforts of all researchers, to provide leadership to technical specialists & farmers, & to develop, test, & evaluate new technologies to be used to address soil & water problems.
Communications
- communicates information from the program to the public.
NPSC (Non-Point Source Committee)
- monitors and evaluates the effectiveness of the SWEEP program in meeting the phosphorus reduction targets.
ON-FARM DEMONSTRATION
- Tillage 2000
TECHNICAL ASSISTANCE
- provides field level professional conservation advice
SOIL CONSERVATION MANAGEMENT INCENTIVE
OSCEPAP II (The Ontario Soil Conservation & Environmental Protection Assistance Program)
TAP (Technology Assessment Panel)
- coordinates & centralizes stock of technical data on soil & water conservation technology.
CONSERVATION INFORMATION BUREAU
- collect, catalogue, & distribute soil management & conservation information
SOCIO-ECONOMIC EVALUATION
- graduate student program
FLEA (Farm Level Economic Analysis)
- to determine cost effectiveness of technologies
TED (Technology Evaluation & Development)
- develops, adapts, evaluates, & validates new or untested technology related to soil properties & P movement from cropland to water systems.
PDW (Pilot Demonstration Watershed)
- evaluates the effectiveness of implementing comprehensive soil & water conservation programs on all farms in a few selected small pilot watersheds.

Figure 1. Components of the SWEEP Program

appreciation of the measures necessary to fulfil the TED mandate. It was clear throughout the entire process that allparties agreed that the TED program should result in the following three tangible products:

1. New or Improved Technologies and Farm Conservation Systems - The TED program was to develop new or improved approaches to farm practices which would result in the conservation of soil and the maintenance of water quality. Many activities contributed to the fulfilment of this portion of the mandate, ranging from small scale studies to alleviate problems with existing conservation technologies (such as pest control and fertility management) to larger scale studies looking at combinations of new technology and practices into potential farm management systems and management of farm field variability.

2. Improved Data on the Environmental and Economic Impacts of Conservation Farming Systems - As the study progressed it became abundantly clear that comprehensive monitoring of the water quality impacts of the farming systems studied under TED was not feasible. Early in the program decisions were made to rely on other components of SWEEP to produce estimates of the reduction in phosphorus and sediment loss due to the implementation of various farming practices. The Pilot Demonstration Watershed project, in particular, was designed to collect data at the field scale. The TED program focused on obtaining more qualitative or relative measures of the environmental benefits of the farm technologies tested on strips and small plots. Similarly, with regard to the economic costs and benefits of the farm technologies, the role of TED was a cooperative one in providing data to the Farm Level Economic Analysis (FLEA) for review.

3. A Solid Base for the Transfer of Farm Conservation Technology to a Wide Range of Ontario Farmers - All parties agreed that it was crucial to build strong links between practising farmers and TED research activities. Benefits flowing in two directions were cited in support of this strategy:
   - researchers would benefit through the input of practising farmers which would ensure that TED research was relevant to current and significant challenges being faced by the end users of the research results; and
   - farmers would benefit through first-hand involvement in the research, would gain greatly improved understanding of the limitations and opportunities associated with the technologies and would be better prepared to adopt and adapt these technologies.

   This strategy of farmer involvement was also seen to have the potential to develop a broad base of skilled, well-informed peers who would be able to encourage other farmers to try conservation farming.

3. STUDY APPROACH

This report section briefly describes the process used to plan and manage TED and discusses two important factors which influenced that process: the "System" or context in which TED was planned and managed; and the importance placed on cooperation and consensus building among farmers, researchers, extension personnel and administrators during the process.

3.1 TED PLANNING AND MANAGEMENT PROCESS

The planning of the TED research program began in February of 1987. Each of the five field seasons, theoretically available for research under the TED program (1987-1991), was considered to be extremely valuable to the success of the program. For this reason, great effort was made to identify high priority research projects which would begin in 1987. At the same time great care was taken not to hastily initiate research which might later prove not to be cost effective in meeting the overall goals of the TED program. Thus a comprehensive and systematic planning process was set into motion immediately with the short term goal of identifying and beginning high priority research in the fall of 1987. Complete details on each step in the research planning process of TED are available in separate documents (Appendix A). Highlights of the TED planning process are shown in summary form in Figure 2.

Three major categories of activities are shown in Figure 2. The core activities are the planning and program review activities which were most intensive at the beginning of the research program but which continued on for the duration of the program. A second fundamental category of activities shown on Figure 2 are the formal reporting and approval processes involving TAP and the technical and management committees. No major program decisions were made without the review and approval of these committees. The third, and most important component of TED activities, was the actual research conducted. The 53 individual research projects completed under TED are represented in a greatly simplified format in Figure 2. Complete details on the rationale and timing of each of the individual research projects are contained in the annual reports and workplans of the TED Subprogram.

The process shown in Figure 2 was designed, and continued to evolve, in response to the overall system in which the TED program had to function. The management of the program had to be systematic and comprehensive in order to ensure that the research funds were well spent and that useful results were obtained. The extensive consultation involving farmers, researchers and administrators was necessary to ensure that the program direction remained relevant and to maximize the opportunity for each of the parties to learn from the experience and knowledge of others. The following sections of the report briefly explain the TED systems approach and the steps taken to ensure maximum benefit from the consultation between parties.

3.2 SYSTEMS FRAMEWORK

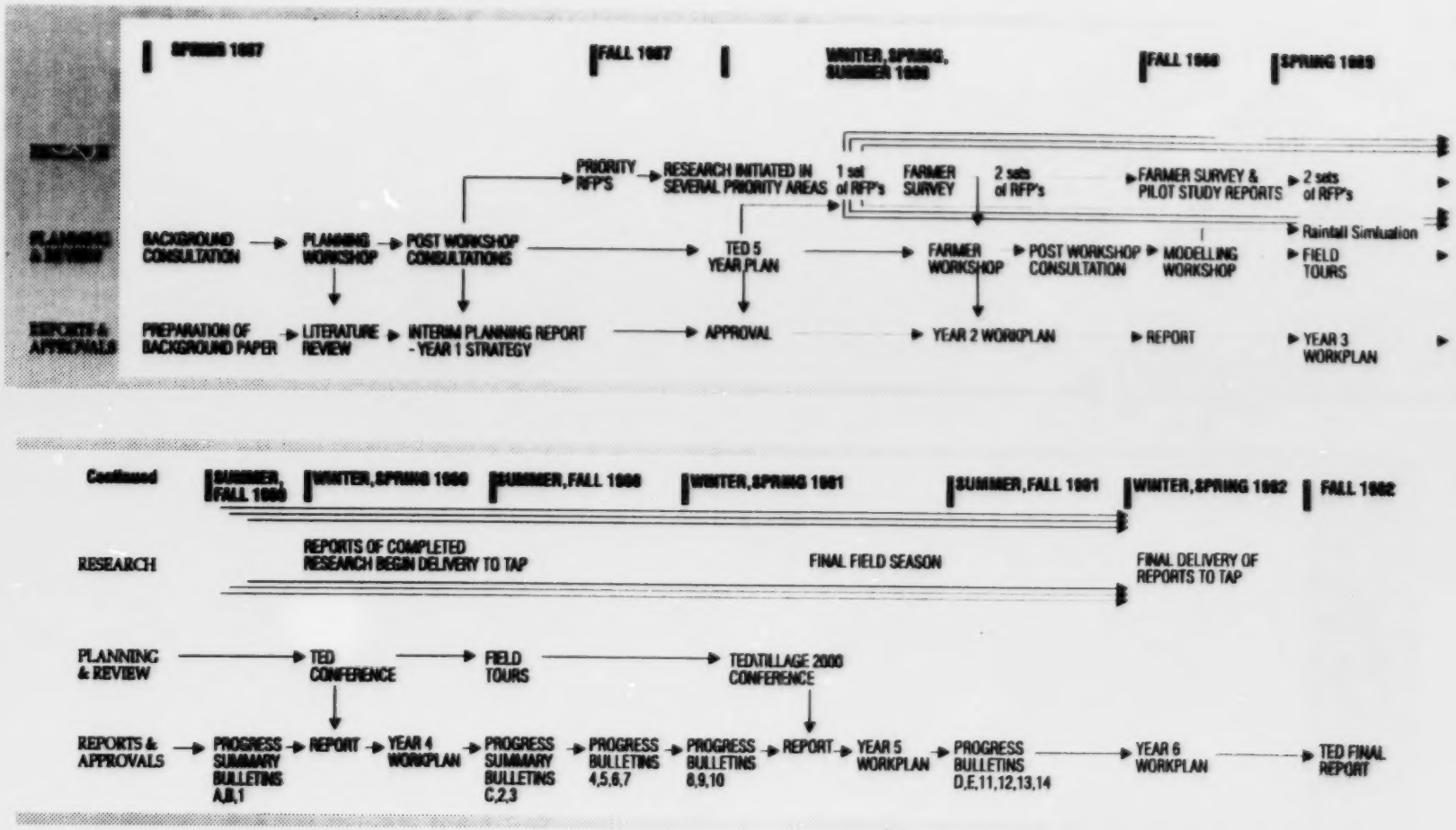
In the initial program stages a conceptual model, or systems framework was developed which defined the components of the TED subprogram. The framework described the boundaries of the subprogram which was to provide research into technological solutions to the phosphorus, erosion, and productivity problems as defined by existing soil and land management systems or practices. The framework also established the link between providing technological alternatives and the adoption and implementation of those solutions. TED was intended to provide the base for such technology transfer.

The TED Planning process stressed the importance of viewing the program in the context of a broader system (Figure 3). This Systems Framework served to emphasize the interrelationships among the various parts, the ecological and environmental conditions, farm management alternatives, and the social and economic aspects, which were important to attaining the TED objectives. The Framework provided a reference guide in the planning and management of TED. The institutional design of SWEEP, its inter-related subprograms, the practical focus of the TED research mandate were all key parts of the Framework. Of particular importance was the objective for TED "to develop a basis for technology transfer and public awareness". The following sections relate the TED experience in the broader context of technology transfer and farm management.

3.3 TECHNOLOGY TRANSFER CONSIDERATIONS

One of the objectives of TED was to "develop a basis for technology transfer and public awareness". While this might be interpreted in a narrow sense as providing research results which could then be "transferred" to the

Figure 2: TED Planning Process



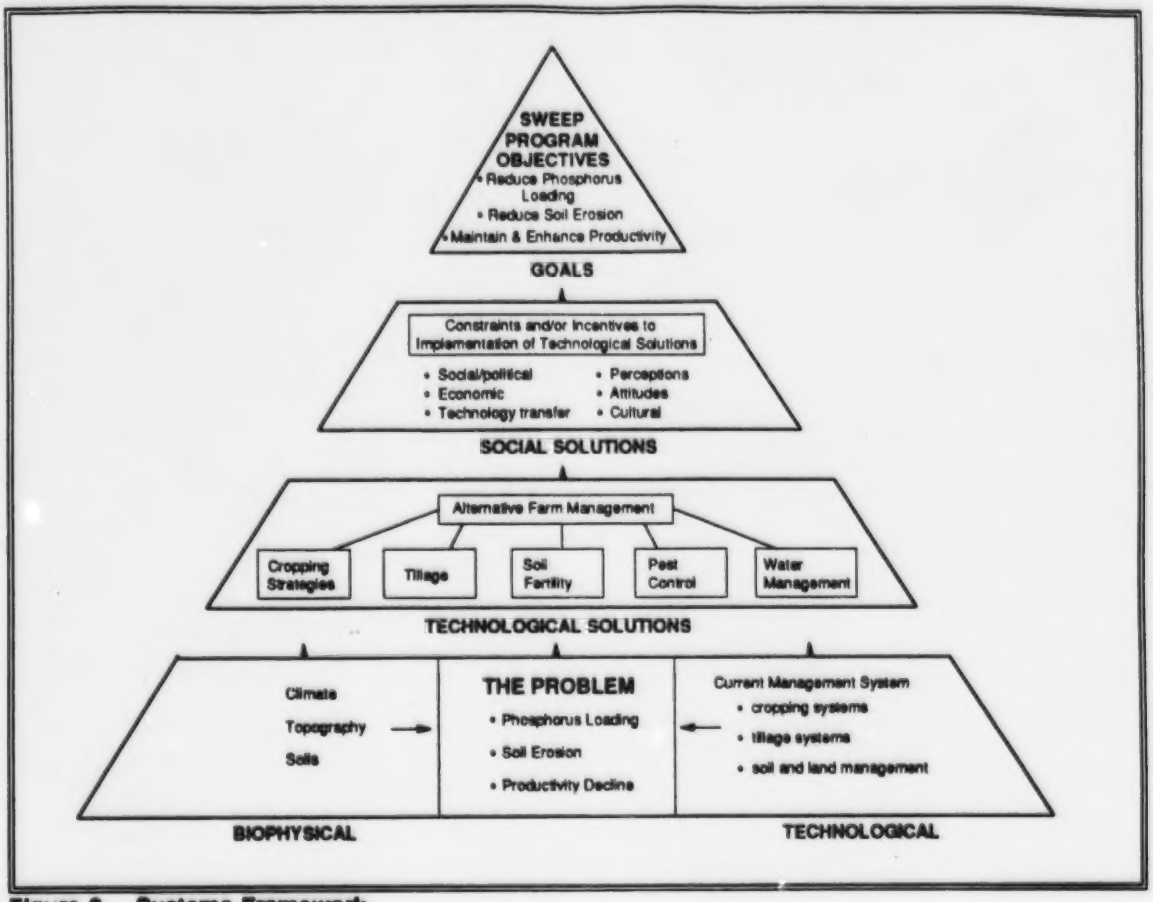


Figure 3. Systems Framework

farmer, current understanding of the technology transfer system demanded a broader interpretation as the basis for TED planning.

In recent years, the technology transfer literature has been critical of what has been termed the "top-down" transfer model. In this "TD" model, information is transferred more or less stepwise, through publications, meetings, advisory services and farm experimentation, from researcher to field specialists and then, with the aid of extension workers, to innovative farmers. From there, it is assumed that the technologies will be diffused to the general farm population. Research and extension are separated institutionally creating barriers to information flow downward to farmers and upward from farmers to research planners.

Alternatives to the "TD" model generally call for a shift to a "farmer-driven" system. Some of the factors which are stressed in the latter system are:

- farmers must be more integrally involved in the research planning process and research program;
- given the unique character of each farm and the risk involved in moving from conventional to conservation or sustainable farming, the technology transfer system needs to respond to individual farmer needs;
- links between researcher and farmer should be designed to ensure mutual understanding and mutual learning; and
- farmers should be encouraged and helped to experiment with promising technologies.

A number of initiatives were taken in the planning and management of TED in response to the recognised need to move toward a "farmer-driven" system of research and technology transfer. The institutional design of SWEEP and TED, in which knowledge development (research) and knowledge application (technology transfer) could be

brought together provided a unique opportunity for moving toward such a system. The experience provided a number of insights into how links between researchers and practitioners might be improved in a way to enhance both research planning and application of research results. This experience and the insights provided by it are discussed briefly below.

3.4 THE TED WORKSHOP AND CONSULTATION PROCESS

During the first four years of the program planning workshops were held which involved farmers, researchers and representatives from participating agencies. The workshops were the central focus of the planning process and each was designed to meet particular needs.

In addition to the formal workshops, a number of smaller, informal expert group meetings were held to fine tune some of the research projects and ensure their relevance to addressing the challenges faced by farmers.

TED PLANNING WORKSHOP

The first step in the planning of TED was the preparation of a background paper. The paper was prepared for TED by the University of Guelph Centre for Soil and Water Conservation (Appendix G). The purpose of this paper was to summarise and identify gaps in the current knowledge of erosion processes and of farm management alternatives. Following the preparation of the background paper a workshop was held to plan the research program. The objectives of the workshop were to:

- initiate dialogue and co-operation among the participating farmers, researchers, agribusiness, extension, and government agency personnel; and
- draw on the wealth of experience available to evaluate the background review, and from it develop a research program and workplan.

Discussion concerning problems centred around four physiographic regions which are briefly described as follows:

1. Flat to undulating very fine textured soils of southwestern Ontario, including most of Essex and Kent and parts of Middlesex, Lambton, and Elgin (flat/clayey).
2. Flat, undulating and gently rolling coarse-textured soils in Norfolk and parts of Brant, Elgin, and Oxford (flat/sandy).
3. Rolling, medium textured upland soils of Middlesex, Waterloo, Perth, Oxford, Wellington, and Dufferin (rolling/loamy).
4. Undulating to rolling fine textured uplands of Perth, Huron, Brant, Middlesex, Waterloo, Dufferin, and Wellington (rolling/clay loamy).

The main problems of P-loading, erosion and productivity loss were discussed in the context of each of the regions.

The flat, clay soils in southwestern Ontario were thought to pose a major problem with phosphorus loading. Cash crops which are heavily fertilized, and the need for rapid overland drainage on the fine textured soils lead to high amounts of suspended solids and P in the various creeks and rivers draining the area. Due to low velocity of surface runoff, water erosion does not appear to be a significant problem on these soils.

In the region with flat, sandy soils, wind erosion was judged to be the predominant problem. Low organic matter and clay contents and low moisture holding capacity in the sandy soils lead to easily detached soil particles. Consequently, soil and fertility losses are high.

Water-caused soil erosion, subsequent productivity loss and water quality problems were considered to be the dominant problems on the rolling medium and fine textured uplands. Soil particles, particularly the finer fractions, are carried downslope, and the resultant loss of nutrients, water holding capacity, and soil structure can lead to productivity decline. As well, a certain portion of the eroded soils and associated P are carried off into drainage waters, creating a P load. It was assumed the erosion and productivity decline are a greater problem on these lands than the P loading.

The first Workshop identified several high priority research projects which, after approval by TAP, were initiated in the Fall of 1987. This workshop also provided for development of the "Five Year Plan" tabled in January of 1988. Approval of the plan by the SWEEP management committee permitted the TED program to be launched in earnest with a full series of requests for proposals for research issued in the spring of 1988.

3.5 THE TED FIVE-YEAR PLAN

The research program proposed in the Five-Year Plan was developed from analysis of the Background Paper and information arising from the Planning Workshop and discussion with various expert groups. The choices among the many research topics suggested were made according to a number of criteria which were weighted to reflect their relative importance. The criteria and weights are shown below:

A. Areal extent of the problem 10
B. Severity of the problem 10
C. Understanding of the problem 10
D. Probable impact on TED objectives 25
E. Probability of adoption 10
F. Links to other research (TED, other in region) 20

The total score of any research topic was multiplied by the following factors to determine the final ranking:

Multipliers:
G. Cost of research vs. likelihood of results 0.1-1.0
H. Limitations under TED 0.1-1.0

Suggestions for research, arising from the Background Paper, Planning Workshop and discussions with experts were assessed according to the foregoing criteria (Table 3.5-1). In some instances, it was not possible to rate a topic since its importance was dependent upon the results of preliminary research. In a number of cases, topics rated low because of the short time available to undertake the type of research in question. This plan was presented to TAP. TAP suggested several modifications in priority rankings. The focus, specific topics and relative weights continued to evolve throughout the process.

Table 3.5-1. Research Priorities for TED

Topic	Priority Rating *
1. Farm Management Systems	
1.1 Management of variable fields	High
1.1.1 erosion and phosphorus loss from slope positions	
1.1.2 erosion and phosphorus loss under various management systems	
1.2 Influence of weather on choice of technologies	Medium
1.3 Survey of innovative farming practice	High
2. Cropping Strategies	
2.1 Main crop alternative	Low
2.2 Cover crop options and management in corn-bean rotations	High
2.2.1 upland soils	
2.2.2 lowland soils	
2.2.3 field trials arising from foregoing	
2.2.4 special studies (new varieties, management innovations)	
3. Tillage Options	
3.1 Residue management	Medium
3.1.1 upland soils (emphasis on erosion)	
3.1.2 lowland soils (emphasis on P movement)	
3.2 Equipment modifications and development	?
3.2.1 reduce axle loadings	
3.2.2 computer-control of inputs for management of variable fields	
3.3 Contour tillage	Low
4. Fertility Management	
4.1 Nutrient distribution under conservation management practices	
4.2 Manure management options under conservation farming	
4.3 Use of anhydrous ammonia in relation to P movement	
4.4 Fertilizer placement (equipment: modifications and development)	
4.5 Benefits associated with fertilizer placement: emphasis on phasing into conservation farming	
5. Pest Control	
5.1 Weeds under reduced tillage	High
5.1.1 chemical control: mixes, rates, time, stage of main crop	
5.1.2 control of problem weeds	
5.2 Integrated weed management: biological, cultural, field scouting, time effects	Medium - High
5.3 Threshold weed levels in terms of yield and crop management	Medium - High
5.4 Field trials arising from foregoing	High
5.5 Other pests (diseases insects, molluscs)	?
6. Water Management	
6.1 Land reshaping: lowlands	Medium
6.2 Increased infiltration and percolation: tile drainage, cultivation, cover corps	Medium
6.3 Structures: sediment ponds, french drains, buffer strips, berms	?

Table 3.5-1. Research Priorities for TED

Topic	Priority Rating *
7. Problem Understanding, Research Methods	
7.1 Erosion related to slope position	Medium
7.2 P-delivery models/rations	N/A
7.3 Structural degradation	?
7.3.1 pilot study; lowlands	
7.3.2 effect on phosphorus; yield	
7.3.3 remedial measures	
7.4 Conservation tillage and water quality; macropores, improved structure and impact on herbicide and N movement	?
7.5 Remote sensing to monitor erosion and P movement	Medium
7.6 Wind erosion; seriousness in P movement	N/A
7.7 Allelopathic effects: causes, effects, remedies	High

? Priority not assessed - pending results of other research

3.6 Research Plan Review and Progress Reporting

After the initial planning workshop, TED management continued to meet with small groups of experts to elaborate on research topics within a category. These groups included farmers and researchers, and often agribusiness and government agency representatives.

Three major workshops and conferences were held to report on the interim results of the research and obtain comments and suggestions for refinements to the program. In addition, a number of small informal meetings were held on special topics. Some planning exercises continued up to the third program year where research priorities were revisited. At this point no major shifts in the program could occur; however, identified gaps in research topics or in data collection were addressed through new contracts or amendments to existing work. Detailed reports on the purpose and outcome of each of these monitoring and feedback exercises are listed in Appendix A. A brief description of each appears in Appendix B.

In an attempt to reach a wider group of concerned individuals with the progress of the subprogram, the program managers produced factsheets. The factsheets were usually two page descriptions of the relevance of the research project, its scope, objectives, and its results to date. These were distributed to individuals and organizations who had been closely involved in TED as well as a large group more peripherally involved in SWEEP. The circulation list at the end of the project contained nearly 450 names, 235 of whom were identified as farmers. These activities were in addition to the formal process of annual TED Reports and workplan presentation to TAP. As each individual research project was completed, the responsible contractors also made a presentation to TAP.

3.7 Farmer Involvement

The TED subprogram was viewed as a link between mainstream research and the farming community and as such, placed emphasis on the involvement of farmers in the planning, as outlined above, and carrying out of research. The objective of soil erosion control was to be achieved by affecting changes in farm management practices within particular watersheds. Hence, farmer involvement was essential to ensure that research reflected farmer needs in various geographic areas of the Lake Erie basin. The research was to be relevant to commercial farm operations, and would necessarily involve studies carried out at this level.

One of the first projects awarded under the TED research program was a review of the soil and water conservation research being conducted on the farms of the early innovators in conservation farming practices. The review identified a number of areas where TED funding and scientific support could assist farmers in addressing problems which were delaying the wider adoption of soil conserving practices. The review also identified a valuable network of farmers from all parts of the SWEEP study area who were willing to advise TED researchers and provide research sites and farm management expertise for the research to be done.

This review was followed by a farmer workshop held in London in March, 1988 (see Appendix B) at which farmers' questions and concerns about TED research were addressed and their comments incorporated into the research planning exercise.

Producers continued to be involved with workshops throughout the program, providing interim review of the program. Individual producers and representatives of producer organizations were invited to participate in workshops and conferences which presented findings of the research even as it was in progress.

The TED program assisted farmers interested in doing research in conservation technologies, by linking them to people who could assist them with data management, experimental design, and contractual requirements of the program, such as reporting. In this way, TED provided support for farmer-initiated research projects.

The extensive and continuous input of knowledgeable and concerned farmers most certainly had a profound impact on the subject matter and approach to research within the TED program. Every effort was made to ensure that the farmers, who put so much into the program, received something valuable in return. The model which was adopted for the TED program was one of mutual cooperation and learning between farmers, researchers and program administrators. The TED Subprogram budget and schedule did not allow all farmer concerns to be addressed, and in some cases, despite the best effort of farmer and researcher, no technically adequate means of investigating farmer concerns or claims could be developed. Some of the research that was conducted proved to be inconclusive and left farmers and scientists with differing opinions on the effectiveness of certain practices. In a program of this nature and scale, there are bound to be disagreements and disappointments. However, there can be no question that in the relatively short time available to it, TED, as part of the larger SWEEP initiative, played a significant role in improving and increasing the communication and understanding between farmers, researchers and administrators. This improvement in communication and cooperation between these partners is an important legacy of the TED and SWEEP programs.

The contribution of farm producers to all aspects of the program is greatly appreciated. Cooperators in the research, the producer survey (review of farm-based research and development), and the weed survey components of the research program are listed in Appendix C.

4. ADMINISTRATION AND ACCOMPLISHMENTS OF THE TED SUBPROGRAM OF SWEEP

This section of the report presents a brief discussion of the administration of the TED subprogram and presents some general statistical information. It also focuses on accomplishments under the three general objectives of the TED subprogram:

- Evaluation of conservation farming technology;
- The development of conservation farming technology; and
- Development of a sound base for the transfer of technology from the scientific and education and extension community into the farming community, as well as the transfer of information among members of the farming community.

As part of the TED approach to improved technology transfer and research planning some attention was paid to development of a farm decision support framework. This work is summarised in Section 4.5.

4.1 SUBPROGRAM ADMINISTRATION

The TED program spanned seven government fiscal years from 1986 to 1992. However, these fiscal years covered only five full agricultural growing seasons with the first summer available for research occurring in 1987 and the last summer for field research occurring in 1991. During these five field-seasons, 53 individual research projects were initiated, monitored and completed. These projects ranged from small-scale short-term projects with budgets of less than $10,000 to multi-year, multi-phase projects with budgets in excess of $250,000. Research projects were initiated in response to the identified research needs after a detailed planning process which involved all stakeholders. Additional research was commissioned throughout the life of the subprogram in response to the findings of earlier studies and new concerns raised by stakeholders.

Funding for research was allocated through the use of two major processes:

1. Request for proposals; and
2. Consideration of unsolicited proposals for research within the mandate of TED.

Of the 53 research projects funded by TED, 21 (40%) were awarded in response to the formal Request for Proposal procedure, while 32 (60%) were awarded as a result of unsolicited proposals. Work conducted as a result of unsolicited proposals had to be justified by a demonstrated need for the knowledge which the work would provide. This need was often demonstrated by groups of farmers getting together to identify a common problem or by developments in research conducted as a result of a competitive proposal leading to suggestions for further study. Many of the unsolicited proposals were fairly small projects. This is reflected in the percentage of research funds allocated to unsolicited proposals (56%) and solicited proposals (44%). Fifty-three individual research projects were conducted under TED for a total value of $3,571,781 bringing the average project value to $67,392. Twenty-one solicited proposals were awarded with a total value of $1,582,284, for an average value of $75,347 per project. Thirty-two unsolicited projects were supported with a total value of $1,989,497, for an average project value of $62,172. These figures demonstrate that an appropriate balance was kept between solicited and unsolicited work and ample opportunity was provided for competitive funding of research.

Research funding was allocated between three sectors of the economy: institutional, including universities and provincially-supported research foundations; private sector, which includes individuals and for-profit corporations; and farmer initiated joint ventures between institutional and private sector. Figure 4 shows the relative proportion of research spending for each of these sectors. This Figure shows that there was a nearly equal split between institutional and private research funding and that farmer initiated joint ventures accounted for a significant portion of the funding. The TED subprogram was given a mandate to focus on research conducted at the farm scale. Figure 5 shows that nearly 78% of all the research money spent during the TED subprogram was spent on projects which were conducted on viable commercial farms. In addition, an additional 5.5% of the research money was spent on studies which used a combination of farm and research station resources. Nearly 14% of the money spent was allocated to studies conducted in laboratories or to surveys of innovative farmers and their experience with farm conservation technology.

While it was not an explicit criterion for the distribution of research funds, the management of the TED subprogram was sensitive to the fair distribution of research funds across a wide number of contractors. Figure 6 shows the percentage of funding allocated to each of the major contractors involved in research under the

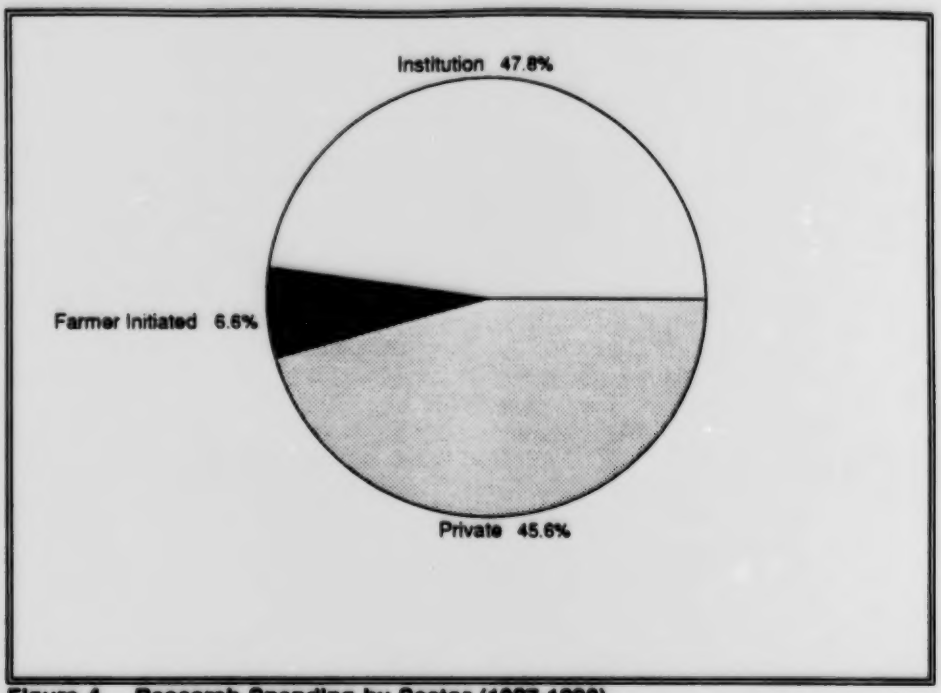


Figure 4. Research Spending by Sector (1987-1992)

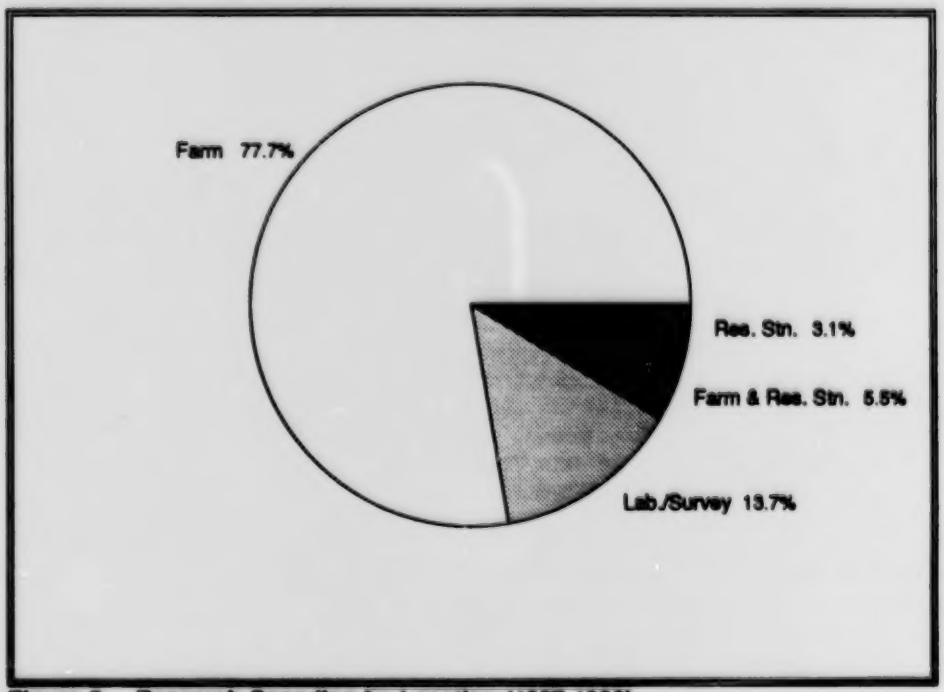


Figure 5. Research Spending by Location (1987-1992)

TED subprogram. The University of Guelph, by virtue of their preeminent position in agricultural research in southwestern Ontario, did receive a large portion of the research budget. However, it is important to note that two-thirds of all research money spent was allocated to research institutions, private-sector research firms and individuals not affiliated with the University of Guelph. During the course of the TED subprogram great effort was made to further diversify the base of research contractors. Unfortunately, despite repeated efforts, the subprogram managers were unable to elicit technically acceptable research proposals from any contractors outside of the group identified in Figure 6.

In addition to conducting individual research projects a considerable amount of time and effort was spent in managing and administering the TED subprogram. Illustrated in Figure 7 is the breakdown in annual spending on four components of the TED subprogram. This Figure is based on federal government fiscal years which extend from April 1st to March 31st and which cover a complete growing season. Fiscal year 1986 and 1992 were only partial years and no field research was conducted in either of those two years. Costs associated with the equipment component of TED include purchasing, maintaining and transporting many pieces of conservation farming equipment. This equipment was made available to all interested parties to use on a demonstration basis and to assist in the TED research. The availability of this equipment and transportation of it made it possible for a wide range of farmers to test various conservation farming implements at no cost or financial risk. This component of the TED spending was extremely valuable in encouraging farmers to test new conservation technology and consider adopting the use of alternative farming methods.

The administration component of the TED spending relates to costs incurred by the scientific authority and support staff at the Harrow Research Station. This includes extensive costs for infrastructure support, printing of report copies, laboratory services, travel and associated expenses. In order to encourage research at the grass roots level a great deal of clerical and technical support was offered free of charge to interested parties without access to such resources. This support was valuable in facilitating farmer groups involvement in the TED program and in the determination of direction of research projects.

The management component of the TED spending as shown in Figure 7 includes all the costs associated with the involvement of the Project Managers. The Project Manager's role was to support the scientific authority in the planning, delivery and control of this large research project. The costs include professional time required to plan, manage and track each of the 53 individual research projects conducted under TED, as well as manage the overall project and budget. A description of the tasks involved in the awarding and monitoring of research contracts appears in Appendix D. This required three, virtually full time, project coordinators with Master's level agricultural degrees. Project coordinators were assisted by senior scientists and project administrators who spent significant amounts of time advising on program design and management. Management activities also included public information tasks such as, erecting signs at research plots, producing progress summary bulletins, and responding to specific information requests from the media and public. A large portion of the management costs were related to the planning and conducting of numerous workshops which involved all stakeholders in setting and reviewing the research priorities of the TED program.

Like the scientific authority, the TED project managers also provided extensive support services to research contractors. This included advice on the scientific design of the studies, assistance with data analysis and report preparation, as well as review of final reports and assistance in preparation for report discussion with the Technical Advisory Panel.

4.2 Evaluation and Development of Conservation Farming Technologies

Two of the major objectives of the TED program were to:

1. Evaluate the environmental impact of conservation farming technologies and the economic costs and benefits of implementing such technologies; and
2. Develop new technologies and enhance existing technologies.

Each of the 53 research projects conducted under TED can be classified according to whether it was designed to meet one or both of these objectives.

Components of the farm conservation technologies to be evaluated included the impact of the technology on the net return to the farmer through a change in crop yields or input or fixed costs. Where applicable, each of these parameters was evaluated in the TED research. For the sake of simplicity, the approach taken was one of recording differences between the conservation technology and conventional technology. Where a conservation technology was being compared to conventional technology, yields for both systems were taken by the most accurate means practicable. The following components of the cost of production of the crop were tracked in all studies where they differed for the technologies being tested:

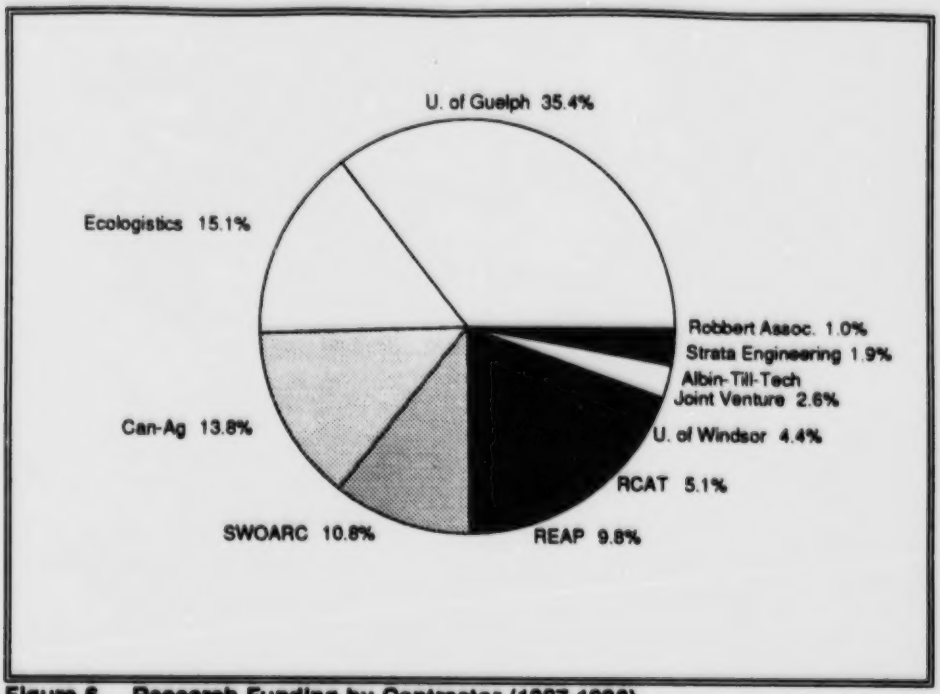


Figure 6. Research Funding by Contractor (1987-1992)

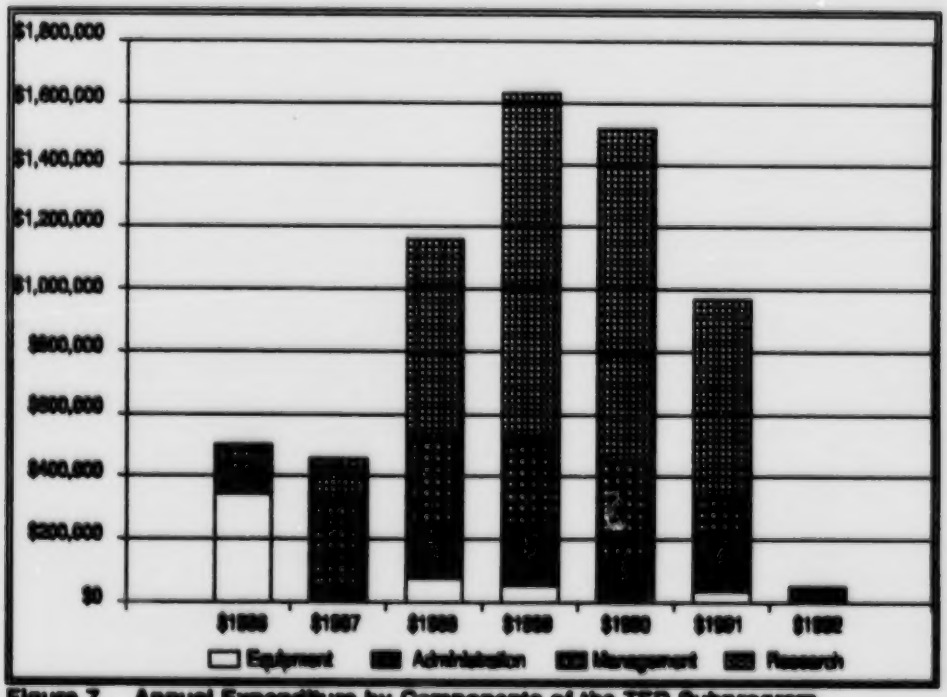


Figure 7. Annual Expenditure by Components of the TED Subprogram

1. Input costs (e.g., the cost the cover crop seed, the cost of additional fertilizers or alternate herbicide mixes);
2. Labour inputs (e.g., time required to conduct additional field work, such as interrow cultivation); and
3. Capital costs associated with acquiring the necessary equipment. Where possible and applicable the cost of any required implements, as well as the implications for required tractor size to move the implements were noted.

These data allow for the cost accounting of one crop production system against another to determine if the implementation of conservation practices will result in additional costs to the farmer. These data were collected for the benefit of the farm-level economic analysis program of SWEEP. This subprogram will be using these data and data from other components of SWEEP to conduct the economic analysis of various conservation practices. Within the mandate of the TED subprogram, the major indicator of the economic impact of a conservation practice was the impact of the practice on yield. Where yield impacts were insignificant and no additional input or machinery costs were required, the conservation technology was considered to be at least cost neutral for the farmer. Anecdotal information was collected on other benefits of implementing the conservation technology, such as any requirements for reduced herbicide rates or simplified and streamlined farm management systems.

The other major component of evaluation within the TED subprogram relates to the impact that the conservation farming technologies will have on the loss of sediment and phosphorus from agricultural fields. While a portion of the TED research was conducted at the field scale, it was not feasible to monitor whole fields for water quality impacts and sediment loads. The primary method of measurement for estimating the impact of conservation technologies on soil erosion and phosphorus loss was the degree of soil cover which each of the technologies provided. Where applicable, standard soil cover measurements were made for each technology being tested. While such a measure does not provide information on the absolute impact of the conservation technology in terms of the amount of phosphorus or sediment prevented from entering waterways, it does provide a relative index between conservation technologies. All else being equal, the greater the amount and the longer the duration of soil cover possible under a technology, the greater the improvement in the quality of water in the watershed. There were a number of specialized studies conducted within TED designed to evaluate in more detail the environmental impact of conservation technologies. These studies have been discussed in Section 4 of this report. As an example, extensive measurement of ^{137}Cs was done to track and monitor the movement of soil in response to various tillage systems and field positions. In addition, fully monitored field scale studies were conducted on sites in the rolling upland regions and the low clay plain regions of the province to determine at an individual field-scale level the impact of conservation technologies on phosphorus and sediment movement. Such field-scale studies are extremely difficult to implement and are reliant upon natural weather events to provide useful data. To supplement these studies and provide further information for use by other components of the SWEEP program, rainfall simulation was conducted on a number of sites. Rainfall simulation on a 1 m^2 plot can not be expected to give reliable measurements of the watershed level impacts of conservation technologies. However, it does provide a useful index of the effectiveness of various technologies at controlling erosion and phosphorus movement.

4.3 Technology Development

The second main thrust of the TED program was to develop and improve conservation technologies. This portion of the mandate was interpreted to include troubleshooting and refining within existing conservation technologies, as well as the development of new tools and resources which would allow for wider adoption of conservation technologies. Not all of this development work provided data which were useful for evaluating the impacts of conservation practices. However, all of the work did contribute in some meaningful way to increasing the options of farmers using conservation technology. Much of the work which addressed this objective was identified as high priority by the various farmers involved in the planning process of TED. Of the 53 research projects conducted under TED 31 can be classified as having important technology development components. These projects ranged from small equipment modification work, such as the preparation of new planting equipment for testing on commercial farms, to extensive development and testing of optimal herbicide systems for use in conservation tillage.

A portion of the TED research (seven of the 53 projects) was directed at understanding basic processes which would allow for wider adoption of technologies which were known to be environmentally and economically beneficial. Examples of this type of research include the evaluation of corn hybrids for use under no-till conditions and the study of yield reduction effects of crop residue. This type of research did not provide information on the economic or soil and water quality impacts of conservation technology, however it was deemed to be extremely important in that it could potentially provide information

which would allow for the wider adoption of technologies which are known to have a beneficial impact on soil and water qualities. In all, 46 of the 53 projects conducted under TED can be identified as having provided useful data for evaluation of the economic and environmental impacts of conservation technology.

4.4 The Development of a Technology Transfer Base for Conservation Practices

A very important part of the TED mandate was to develop a strong base for the transfer of technology from the agricultural research and extension community to farmers and also to build upon and enhance the farmer to farmer transfer of technology. The importance given to this part of the mandate is reflected in the large number of farmers involved in the planning and management of the research conducted under TED. By the completion of the project the TED mailing list contained the names of 235 individuals who classified themselves as active farmers. Of these 235 individuals, 148 had been involved in some component of the TED research. This involvement ranged from responding to surveys on weed management problems and solutions under their particular conservation systems to the conception, design, implementation and analysis of entire research projects.

Shown on Map 2 are the general locations of the 148 farmers actively involved in the TED program. Farm locations are generalized to the Township level and the size of the symbol is roughly proportional to the number of farmers involved in that geographic area. Efforts were made to involve farmers throughout all parts of the TED study area. Prior to the initiative of the SWEEP subprogram there were a number of strong concentrations of innovative, conservation-minded farmers throughout the study area. The TED subprogram gladly cooperated with and built upon the experience of these groups of farmers. Their effect is evident on Map 2. However, great efforts were also made during the TED program to find and encourage the participation of farmers who were not part of organized groups and who had not yet been recognized for their innovative and conservation minded approaches. Due to the strong effort of TED research contractors and the helpful advice and support of established conservation farmers, many individuals were able to obtain first-hand exposure to conservation farming practices through their involvement in TED research on their farms.

In addition to supporting, strengthening and enlarging the network of farmer to farmer communication about conservation practices, the TED program assisted in the training and professional development of a number of technicians, researchers and research groups. TED research funds were awarded to small independent groups of researchers with limited access to other funding. The seed money provided by TED allowed them to develop their research programs and expand their operations. In addition, TED research money supported a number of post-graduate students during their agricultural research at the University of Guelph. The TED research project was also responsible for holding a number of planning workshops which brought together farmers, researchers and extension personnel to discuss and plan research programs. TED funds were used to support two interactive research conferences which involved farmers, researchers and extension personnel. These TED activities were a small but important contribution to the increasing interest and expertise which continues to develop very quickly in the SWEEP study area.

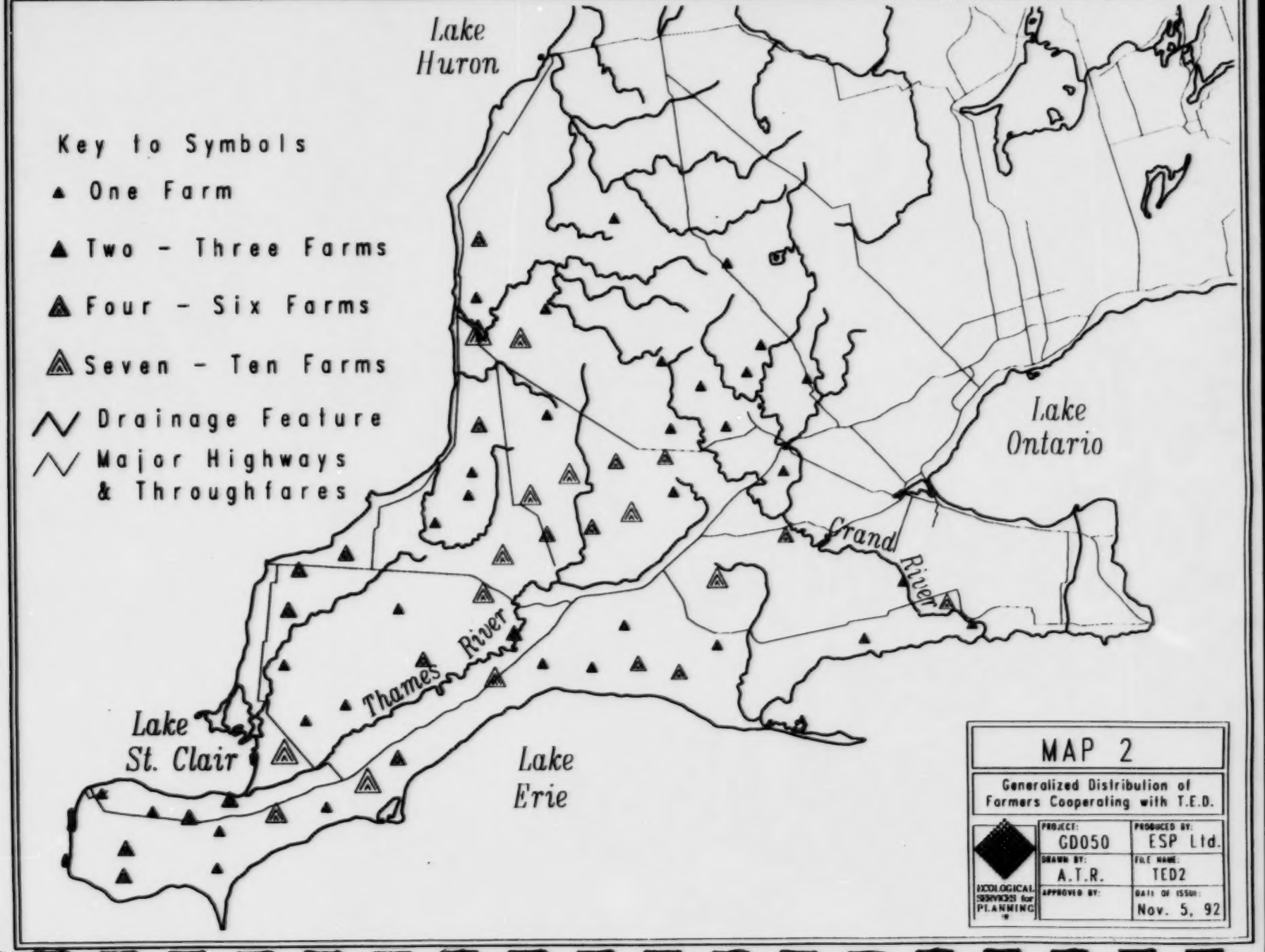
4.5 Development of a Farm Management Decision Support Framework

The myriad of farming conditions - the farmer, the ecology, economic situations, the farming system - together with the wide array of potentially effective technologies creates a highly complex decision problem for a farmer who is considering shifting from conventional to conservation farm management. Adoption of one technology will lead to the need for other changes in the management system.

The farmers involved in TED were, for the most part, those who were already committed to conservation farming. These committed farmers and farmers considering the adoption of conservation practices agreed that tools were required which would assist farmers in reducing the risks associated with the transition from conventional to conservation farming. Means of providing these tools were explored to some extent at the TED Modelling Workshop held in November, 1988. At this workshop it was felt computer simulation of the process and possible implications of farm management decisions might help farmers in choosing the mix of technologies suitable for their unique purposes. As a follow up to this workshop existing computer simulation systems were reviewed. This review resulted in the first phase of the decision support framework project described in the following section.

4.5.2 Requirements of a Decision Support Framework

Extensive review of computer based decision support frameworks and consultation with farmers, researchers and extension personnel led to the following specifications.


Lake Huron
Key to Symbols
One Farm
Two - Three Farms
Four - Six Farms
Seven - Ten Farms
Drainage Feature
Major Highways & Throughfares
Lake Ontario
Grand River
Thames River
Lake St. Clair
Lake Erie
MAP 2
Generalized Distribution of Farmers Cooperating with T.E.D.
ECOLOGICAL SERVICES for PLANNING
PROJECT: GD050
PRODUCED BY: ESP Ltd.
DRAWN BY: A.T.R.
FILE NAME: TED2
APPROVED BY:
DATE OF ISSUE: Nov. 5, 92

The decision support framework should:

- place emphasis on learning through exploratory simulation rather than on prediction or prescription;
- be an interactive tool and process which will facilitate dialogue among various interests and experts;
- have the ability to store, manipulate and retrieve both scientific and farm-specific information;
- be relatively inexpensive and self-contained in a portable computer to maximize flexibility and use;
- be able to use natural concepts and represent agricultural processes that are operational and make intuitive sense to the user, and
- be capable of incorporating new understanding as it is accumulated with model use (ie. a model which becomes increasingly powerful with use, but can be useful with minimum data).

Expert systems, which show promise in providing prescriptions to correct observed symptoms, and existing erosion and econometric models, which help in understanding the farm management system, may be parts of the solution but no single existing system meets the needs outlined. Shortcomings include:

- no existing tool incorporates enough of the agricultural system to give a picture of the agronomic, economic and environmental implications of farm management decisions;
- many systems place too much emphasis on prescribing specific solutions to specific problems and do not allow exploration of alternatives and "what if" analyses;
- incorporating the results of recent research and improved understanding of processes such as plant growth and erosion is difficult, if not impossible, in most existing systems.

An existing approach which showed the greatest promise was developed by ROBBERT ASSOCIATES, and derived from a five year program in Statistics Canada to develop a socio-economic resource framework. Accordingly ROBBERT Associates was awarded a contract to develop the first phase of a Farm Management Decision Support Framework using their existing tools and incorporating the agricultural systems science and experience available through the TED subprogram.

The unique characteristics of the ROBBERT approach are outlined in detail in the project report (see Appendix E.1.3). To assist in managing the development and controlling costs, the project was divided into three phases. The purpose of the first phase was to determine the validity and utility of the approach. The purpose of the second phase was to assess the Framework in a "real farm" setting and the third was to make the Framework available to users - farmers, farm groups, the private sector, extension services, etc. The third phase would make the system "user-friendly" to eliminate or reduce the need for technical assistance in its application. The first phase was completed under the TED contract, the second and third phases were beyond the time and budget resources of the TED program.

Experience during Phase 1 demonstrated the potential of the ROBBERT approach as a learning tool which could be used to explore the implications of various farm management decisions and to "mix" experiential and scientific information. The promise shown by the first phase of the project clearly indicates a potential for meeting the established guidelines outlined above.

RISK AVOIDANCE IN SHIFTING FROM CONVENTIONAL TO CONSERVATION PRACTICE

The initiative to develop a Farm Management Decision Support Framework was an attempt to assist farmers in understanding and reducing the risks associated with the transition from traditional to conservation farming. Unfortunately, the time and funds available in the TED program were not sufficient to allow the decision support system to be developed to a point were it could be tested in a real farm setting. Therefore, the question of how the TED model might be modified to reach the general farming public was not exhaustively addressed under the TED mandate. However, the experience in TED does strongly suggest that the role of decision support tools in advancing the adoption of new farming technologies and systems should be explored further.

A primary value of computer- assisted Decision Support models is in their potential to simulate specific farm management situations and to allow exploration of the impact of the adoption of new or improved technologies. An assumption which would be tested by such models would be that the understanding gained by such exploration would serve to reduce the risk of shifting to conservation management. Since the reticence of many farmers to shift to conservation practices is associated with the perceived high risk of doing so, use of decision support models have the potential of widening the acceptance of conservation practices. While farmers were involved in the planning process and in the conduct of the research, those involved were in large part already committed to conservation farming.

Involvement of farmers in computer simulated exploration could also be a powerful tool in developing a "farmer-driven" technology transfer system. Since the Framework has the facility of including farmer experience as well as scientific information, it thus provides a powerful tool for developing an understanding of research needs. In this way it would provide a structured framework for involving farmers in the research planning process.

The current state of the art in systems design and supportive hardware and software offers new potential for dealing with problems requiring longer term experimentation, such as those explored within TED. Since complex farming systems can now be simulated in "the way that a farmer thinks and responds", it follows that the need for long term as well as shorter term experimentation could be met by farmer-scientist cooperation in which hypotheses could be developed and tested as a part of the normal farm operation. The Farm Management Decision Support Framework project was seen as a step in this direction.

The current incentives being provided by governments for farmer involvement in the technology transfer system and the generally enthusiastic response of farmers to such incentives provides a climate for innovation. The TED model, when viewed as a system which includes both research and technology transfer, provides a basis for development of a "farmer-driven" technology transfer system in which research and practice become integrally linked.

4.6 SUMMARY

The administration and delivery of the TED subprogram relied on a partnership between the scientific authority and the program managers. This partnership proved to be very effective in efficiently dealing with the large number of activities required to deliver such a large research program. The partnership was able to deliver a well planned program which responded to the identified priorities of all parties involved in the program. The planned research was implemented and completed on budget and on schedule making efficient use of a range of research capabilities throughout the province. The available research funds were equitably distributed between research institutions, such as the University of Guelph and the private sector. A number of productive joint ventures between research institutions, private sector contractors and active farmers were encouraged and supported.

Regular review of the program progress with the Technical Advisory Panel resulted in modifications and research enhancements which improved the focus and overall achievement of the program objectives. Communication of research results and opportunity for input was provided to a wide range of interest through the use of Progress Summary Bulletins and research conferences. TED was a long-term, large-scale research project in which communication and cooperation with other program components was crucial. The administrative framework used in the TED subprogram allowed for a great deal of communication and cooperative planning and review to take place. It was the complimentary strengths of the various partners and the strength of the communication process which ensured that the program remained focused in relevant areas and was able to deliver useful results.

5. THE TED RESEARCH PROGRAM

The following sections summarize the findings of the research projects conducted over the five years of the program. The format of this section, follows the research categories established in the TED 5 Year Plan. The reader should refer to Appendix E for a more detailed summary of the individual research projects and to the SWEEP-TED reports for complete methods, results, and discussion. The SWEEP-TED reports are listed in Appendix F.

5.1 FARM MANAGEMENT SYSTEMS

"Farm Management Systems" was identified as one of the research priorities for TED by the participants of the initial planning workshop. It was recognised that some research in this category must be of the longest term possible under TED so priority projects were initiated in the Fall of 1987, prior to the completion of the five year plan. Other projects were initiated in 1988, after approval of the five year plan. The plan presented a list of the anticipated results from farm management systems research, which included:

- a resource base of farm managers with research skills and experience cross - referenced by technology, soil, farm management type and declared interest in future SWEEP studies;
- a set of criteria defining a minimum soil management unit consisting of land forms which can be effectively managed to reduce soil erosion and P movement;
- a measure of risk drawn from existing weather records and expressed as a probability of storm severity, regional location and seasonal distribution of storms, to be used to assess the relative erosion protection of alternative farm management systems.

Five farm management related research contracts were awarded during the TED program. Studies focused on an inventory of farm based researchers, the impact and management of farm field variability, evaluation of an aeration tillage system and on development of a farm level decision support framework. Studies on the relative soil conservation properties of technologies due to weather patterns were not conducted. The priority of these studies was reduced subsequent to review of the five year plan when limitations due to study design, time frame and budget became apparent.

One of the first projects awarded under TED was a survey of conservation practices being tested, revised and adopted by leading farmers in Ontario (Appendix E.1.1). Twenty-seven farmers were included in the study. Participants were chosen on the basis of demonstrated experience in the implementation of conservation practices as part of their overall management system. Five of the participants were engaged in what they termed organic farming systems. The rest of the participants characterised their operations as more conventional, including the careful use of chemical inputs. All participants were motivated by a desire to maintain the health and long-term productivity of their farms, make efficient use of inputs and remain economically viable. This study was valuable to TED in refining the farmer position on research priorities and identifying a resource group of advisors and research cooperators. Farmer-researchers benefitted by making known their need for support in research design, scientific analysis and reporting. The TED program took immediate steps to meet these farmer needs.

Another priority research topic identified in the early planning stages of TED was the management of farm-field variability. This series of projects was designed to take advantage of the excellent research opportunities afforded by the Tillage 2000 research program. The Tillage 2000 program was a part of the Government of Ontario's commitment to the SWEEP program. Tillage 2000 was a long-term, on-farm, field-scale research and demonstration project conducted for five years on approximately 40 farms across the Province of Ontario. Each site included a carefully controlled and laid out research plot on which conventional and conservation farming systems were compared to each other through the use of a number of permanently located sample points occupying the same soil landscape position. This network of established study sites provided valuable research opportunities for the TED program, and the TED funding allowed Tillage 2000 to conduct more detailed analysis on their research sites.

The project arose out of the identified need to better understand the challenges involved in managing farm fields with complex topography, soils and drainage patterns. The project was intended to contribute to the understanding of soil erosion, soil quality and crop productivity processes within complex fields and also to contribute to the development of a management strategy to control erosion and to improve soil productivity. The main conclusions of the project were that large amounts of soil and associated phosphorus are being moved within fields with complex topography in southwestern Ontario

(Appendix E.1.2). The amount of soil and phosphorus moved within a field does not necessarily bear any direct relationship to the amount of soil and sediment delivered to streams. Therefore the crop productivity impacts of soil movement in complex fields can be significantly greater than the environmental and water quality impacts. The greatest portion of all soil movement in fields with complex topography is caused by tillage translocation. Conservation tillage systems which reduce the amount of tillage conducted are effective in reducing the soil and phosphorus movement within fields with complex topography. Crop yields were found to vary across the complex fields in relation to soil properties which can be affected by soil erosion. Use of conservation tillage, particularly in no-till systems, did not result in yield decreases when properly practised on fields of complex topography. This fact and the existence of relatively consistent crop yield patterns across the fields suggest that there are excellent opportunities to develop management systems which will work with intrinsic soil properties to optimize the relationship between crop yield and crop input on these fields. As a result of this research project, some additional work was done on the translocation of soil due to tillage practices. This work is discussed under Section 5.7.

Two TED projects were initiated in 1989 to investigate an alternative farm management system developed by a group of innovative farmers known as the Ontario Biological Aeration Tillage Association (O.B.A.T.A.). The farmers hoped to improve their soil quality by adopting practices which controlled erosion and led to increased biological activity and biomass production. At the same time they wanted to lessen their dependence on off-farm inputs, especially fertilizers and pesticides. Each O.B.A.T.A. farmer developed a farm specific management system, based on a wide range of farm management alternatives. The components of the O.B.A.T.A. system included aeration tillage, reduced tillage, subsoiling, cover crops, crop rotations, foliar spray applications (kelp, molasses and fertilizer) and reduced application rates of herbicides and fertilizers.

The O.B.A.T.A. farm management system was evaluated in two separate TED studies. In the first study, an evaluation of aeration tillage systems (Appendix E.1.5), a consultant attempted to evaluate as many aspects of the O.B.A.T.A. system as possible at seven farms over a three year period. The second study (Appendix E.1.3) examined the role of kelp and molasses in aeration tillage systems over a two year period at two of the O.B.A.T.A. sites from the first study.

Both the O.B.A.T.A. system and the "standard" management system to which it was compared varied considerably from farm to farm in terms of crops grown, availability of manure, and rotation of principal crops. The site to site variability tended to reduce the amount of control of the researchers in the first O.B.A.T.A. study and their ability to statistically validate the results. However, it was recognized that each farm is an independent business operation, and that the farmers are the stakeholders in the business. The farmers must have control over the farm management decisions that affect their livelihood, regardless of the statistical implications.

Over the three field seasons of the research, many of the O.B.A.T.A. treatments appeared to have little or no quantifiable agronomic benefits. Soil fertility, structure and compaction, and microbial biomass did not appear to differ between the O.B.A.T.A. and standard treatments. Soybean yields were similar for both treatments, while corn yields from the O.B.A.T.A. treatments were slightly lower in the first two years of the study and slightly higher in the final field season. Records of inputs and returns showed that O.B.A.T.A. practices were economically comparable to conventional practices.

Rainfall simulations were conducted at four of the seven O.B.A.T.A. farms. Results were not consistent, but overall, they appeared to indicate that the O.B.A.T.A. treatments, particularly the cover crops and aeration tillage under dry soil conditions, resulted in reduced soil, sediment and phosphorus losses, compared to the standard (fall moldboard plowed, no cover crop) treatments.

The second TED study related to the O.B.A.T.A. farm management system attempted to determine the usefulness of spray applications of kelp, molasses or a fertilizer solution (71B), alone or in combination, within the O.B.A.T.A. system. This experiment was located on sub-plots within the other ongoing O.B.A.T.A. study, and took place under more controlled conditions. Experiments occurred during the 1989 and 1990 growing seasons at two locations where the current crop was soybeans and the previous cover crop was rye. The sites received differing treatment combinations which consisted of aeration tillage and/or the addition of a liquid formulation of: "71B fertilizer solution" and/or kelp and/or molasses to the seed or the foliage of the soybeans at specified time intervals.

From the results of this experiment, it appeared that the application of kelp, molasses or "fertilizer 71B solution" liquid formulations at planting or as a foliar application did not significantly affect soybean growth. Although these results were not encouraging, the farmer participants in the study still believe that the spray applications have merit, and continue to use them on their crops. Two of the sites in the first O.B.A.T.A. study showed noticeable yield increases with a kelp, sugar and fish emulsion foliar spray. The yield increases were not significant (due to lack of data points).

Both of the TED studies that dealt with the O.B.A.T.A. farm management system were hampered by the short duration of the research. Positive yield results from the O.B.A.T.A. treatments in the final year of the study could be an indication that the farmers had worked out some of the problems with the system, and were now in a position to make it work to their advantage. While the TED studies did not show the O.B.A.T.A. system to be agronomically superior to the standard management system, it may be a viable alternative to conventional agriculture, offering comparable yields and net returns, while reducing soil erosion and phosphorus losses. Since pasture and manure management are readily included in the O.B.A.T.A. system, it may appeal more to farmers with livestock than those who grow strictly cash crops.

5.2 Cropping Strategies

Erosion can be reduced by keeping the soil covered with crops or crop residues. The use of cropping strategies which provide soil cover throughout the year should not only reduce erosion but also improve water infiltration.

The Five Year Plan identified high priority research topics in the area of cropping strategies relating to cover crop options and their management in corn-bean rotations. The primary focus of research was the management of cover crops: their establishment, elimination, and factors relating to the success of a succeeding crop. The following expected results of this type of research were identified:

- information on new species, varieties and management options for cover crops;
- data regarding the role of cover crops in protecting against P movement and erosion;
- options for natural elimination of cover crops versus the cost of managed elimination;
- the potential for cover crops to provide economic returns of their own.

Given the relatively short time frame and limited funding of TED it was deemed unlikely that research into alternative main crops would be fruitful. However, during the course of TED research some insight was gained into the management of potential problems, such as yield reduction and poor emergence, due to main crop residues under reduced tillage systems.

In general, research showed that cover crops can provide high levels of ground cover. These results were often confounded with the high levels of residue achieved through tillage. Additional cover provided by cover crops in an untilled system is not expected to provide additional benefits in the prevention of soil erosion where residue levels are already high, but they may add biomass and a sink for excess nutrients when these are desired.

Legumes

One of the more widely used cover cropping systems is one in which red clover is underseeded into winter wheat. Unfortunately, the practice of fall plowing of the clover eliminates its benefits for winter and spring erosion control. In the TED studies, fall chisel plowing of the red clover left over 50% soil cover; these levels were reduced the following spring by secondary tillage resulting in low residue levels (<30%) after corn planting. Either fall or spring chemical kill of the clover provided high ground covers (>30%) even after no-till corn planting. Unfortunately, no-tilled red clover residues resulted in lower corn yields and longer time to silking on some sites in some years (Appendix E.2.2).

Research on phytotoxicity (Appendix E.7.8) described in Section 5.7, indicated that red clover appeared to be allelopathic to corn and produced measurable phenolic compounds extracted from soils in the field.

Research (Appendix E.2.3) demonstrated that alfalfa, crimson clover, and hairy vetch were suitable alternative interseedings to red clover. Hairy vetch is drilled into the wheat in mid-May while red clover may be frost seeded into wheat in March. Hairy vetch has potential to climb in wheat so was recommended only where this aggressive character could be controlled by delayed planting in a sufficiently competitive high yielding cereal crop. Under conditions where the legume cover crops were spring plowed, corn could produce relatively high yields without additional N fertilizer.

Oilseed Radish

A cover crop which might be established following winter wheat is oilseed radish, which can produce a high biomass provided it receives a large amount of N. In REAP studies (Appendix E.2.3) biomass ranged from 0.75 to 3.7 T/ha in the fall while Miller *et al.* (Appendix E.4.2) reported biomass ranging from 2.0 to 5.2 T/ha when oilseed radish was planted after spring and winter cereals.

Ryegrass

Ryegrass was successfully established as an interseeding for corn. Seeded at second inter row cultivation, annual and perennial ryegrass varieties established well. The biomass was relatively low (0.07 to 0.85 T/ha, REAP in Appendix E.2.3) but was observed to reduce flushes of annual weeds once the corn canopy opened in the fall. The ground cover benefits detected in this study were largely due to corn residues left over winter which provided 86% residue cover in the absence of ryegrass. The success of establishing a cover crop, such as ryegrass, in corn is dependent on opening the canopy early in the fall, through

either the use of corn for silage, production of an intermediate yielding grain crop, or the selection of an early maturing variety. This need for reduction in the competitiveness of the host crop has been shown to be true where red clover is interseeded in corn as well.

In other studies (Appendix E.4.2), ryegrass established well after winter wheat and barley, and provided higher residue levels (1.1-2.6 T/ha) than when established in corn, as measured in the fall.

Cereals

Fall seeded rye into which soybeans are no-till planted the following spring was examined as a possible system. Establishment of a significant rye cover was best achieved where it was seeded in late August or early September, and it therefore might be used after a winter or spring cereal. Rye production in these systems generally ranged from 1.5 to 3.5 T/ha (Appendix E.2.3, E.2.4) although values as low as 0.5 T/ha and as high as 4.8 T/ha were achieved by the time the crop was to be eliminated the following spring. This system provided an economic advantage to livestock farmers who can use the rye for cattle feed in the form of harvested or pastured forage.

Another study (Appendix E.2.3) which examined the rye-mulch no-till soybean system, found that the rye suppressed early soybean growth and produced plants low in N. This observation was consistent with those of slight yellowing of soybean leaves near the end of June in some years (Appendix E.2.4). The effect disappeared by eight weeks after planting (Appendix E.2.3). Fertilization with N and P produced a positive growth and tissue N level response, an effect not obtained with either nutrient alone.

Establishment of spring oats and barley into soybeans either in crop or post harvest did not produce sufficient advantages of erosion control as indicated by the added soil cover, and the biomass production, to outweigh disadvantages which included a seed cost of from $30 for bin run oats to $68/ha for certified Leger barley (Appendix E.2.1). Fall rye applications in the same manner were slightly more successful in terms of biomass, but probably need to be seeded earlier to provide better success.

Success was achieved in broadcast seeding winter wheat into soybeans (Appendix E.2.3) in a similar manner as described for the cereals above. This technology should be considered a suitable system for establishing no-till winter wheat since it produced fall ground cover averaging 85% compared with 24% for conventionally established wheat and attained similar yields.

Nitrogen Soil Test

Corn following legume cover crops does not consistently respond to additional nitrogen fertilizer. Spring incorporated red clover in particular, produced high soil nitrate levels measured just before N side dressing, when sampling for the soil nitrogen test was carried out (Appendix E.4.2). Further developments in the use of the soil nitrogen test for predicting nitrogen fertilizer requirements in conjunction with N-fixing crops should prove useful.

Temperature Effects

The lack of incorporation of crop residues in a system has implications for plant growth in terms of the reductions in soil temperature and moisture, the production of allelopathic chemicals, and the soil nutrient status.

Typical 24-hour soil temperature regimes were similar in separate studies examining the effects of mulches on soil properties (see Figure 7, Appendix E.2.4; Figure 8, Appendix E.2.5). Temperature extremes on a diurnal basis were moderated by mulch and the temperature curves were flattened to the greatest extent by high residue amounts on the soil surface. The cooler daytime temperatures were shown to effectively slow early crop growth in corn and soybeans.

Corn growth is dependent on the accumulation of soil degree-days, and where crop residues reduced daytime soil temperatures, corn development lagged behind that of corn grown with no surface residues. In one TED study (Appendix E.2.5), maximum differences in development appeared at the 11 leaf stage in corn and the lag was 5.2 days. Removal of crop residue from the row area with the use of trash whippers reduced the developmental delay to 2.5 days. Early season delays in corn development did not necessarily translate into grain yield reductions which were measured as grain yield per plant.

Hybrid Response

On the other hand, TED studies (Appendix E.2.6) found that corn grain yields responded to residues on the soil surface as controlled through tillage and that the yield reduction varied with the hybrid. Those hybrids which performed best in conventional tillage were not necessarily the best under zero-tillage, at the same site. Under no-till conditions, poor performing hybrids suffered delayed emergence and slower seedling growth. In addition, stands under no-till were less uniform for some hybrids in no-till compared with conventional tillage, and final stands were directly related to grain yields. This was in contrast to Fortin's work (Appendix E.2.5) which showed similar stands and similar variability of stand between two different hybrids used in that study.

As a result of these studies, a corn hybrid rating system, based on corn hybrid cold tolerance, was sought. In order to rate the hybrids, laboratory experiments included

measuring number of seeds germinated and number of seeds producing a 1 cm coleoptile at 25°C, as well as the number producing a root and a 1 cm coleoptile at 11°C measured at specific times. The observed relationship between the index of root or coleoptile growth and cold tolerance requires confirmation with field tests in Ontario.

It should be noted that a great deal of knowledge was obtained about cold tolerance of hybrids (Appendix E.2.6). For instance:

- good germination in near optimal conditions is no indicator of germination at other temperatures;
- there is little or no correlation between germination and good early growth at low temperatures;
- cold tolerance cannot be predicted from Ontario Corn Heat Unit ratings; and
- corn hybrid cold tolerance cannot be predicted based on that of the inbred parent.

Moisture Effects

The effects of soil moisture and temperature appear somewhat confounded. Some research (Appendix E.2.5) has suggested that higher soil water contents may be due as much to the absence of tillage as the presence of residues on the soil surface. This statement was based on the observation of significantly higher early season inter-row soil water contents on no-till soil with residues removed (as well as no-till and trash whipped treatments) relative to the conventionally tilled soil.

Soybeans were also observed to have developed differently according to levels of rye mulch (Appendix E.2.4) into which the soybeans had been no-till planted. Reductions in the date of occurrence of stages of development under mulch were at the most 2 or 3 days. In this study, the delay was attributed to problems in planting through the mulch which led to the slow start. Major stages, such as flowering, pod set and harvest maturity were not affected by the rye mulch. By mid- to end-June, much of the rye mulch had disappeared from the soil surface. It was believed that moisture conservation by the rye mulch tended to produce larger nodule mass and more seeds/pod. Moisture conservation on sand and loam soils which was attributed to rye mulch was considered to be of minor importance. In addition, a modelling exercise indicated that very large amounts of mulch would be required to conserve enough moisture to increase soybean yields.

A drying effect on the soil of rye growth in the spring was observed to reduce soil moisture but was considered to be of minor significance on the sand and loam soils tested and under the climatic conditions of the study.

Summary

The TED studies explored a range of management and species alternatives for cover crops and developed the establishment and elimination methods required to successfully incorporate their use into a farm system. The success of a succeeding crop appeared often dependent on using some degree of tillage in the spring prior to planting to provide an optimal seed bed environment in the presence of crop residues. Pushing residue aside was also often successful. Cover crops appear to have great potential to contribute to the reduction in soil erosion from cropland as evidenced by the biomass and residue covers which could be achieved over winter.

What is less clear from the research, is the link between main or cover crop residues and yield reduction responses. The effects of residues on soil temperature and soil moisture revealed reduced temperature under residues may delay development but do not necessarily reduce soybean and corn yields. Soil water effects appear to be neither advantageous nor detrimental to crop growth and development.

While a large amount of data on cover crop and crop residue impacts on subsequent crop success were collected, there was sufficient variability between performance on particular farms and particular years to make prediction of the success of a management difficult. Further understanding of the interactions of the system variables would assist in the choice of management among the options available. For example, the development of the nitrogen soil test would be a useful tool in the management of soil fertility with cover crops. Similarly, a screening test may be of help in choosing a corn hybrid that may be better able to emerge at cool temperatures.

A wide range of farmer cooperators were involved in the field oriented research in the cropping strategies area. It would appear that there is a wide range of experience to draw upon from TED and other research in the area of management of cover crops and main crop residues.

5.3 Tillage Options

"Tillage Options" was identified as one of the research priorities for TED in the Background Paper, prepared by the Centre for Soil and Water Conservation, and by the participants of the initial planning workshop. The TED five year plan (ESP, 1988, see Appendix A) presented a list of the anticipated results from tillage research, which included:

- improved residue management techniques for ensuring adequate residue cover on soils;

- additional data on the impact of residue cover on soil erosion and P movement under various soil, climatic and farm management conditions; and,
- equipment modifications to overcome current deficiencies or new equipment designs which facilitate crop residue management while fostering improved crop growth.

Eleven tillage related research contracts were awarded during the TED program. Studies on subsoiling were included in the tillage options category, although the thrust of these studies was on examining the relationships between subsoiling, soil compaction, water movement and yield. The remaining projects dealt with residue management techniques and equipment modifications. Through rainfall simulations, one of the sites in a mulch tillage study (Appendix E.3.8) provided data on the impact of residue cover on soil erosion and phosphorus movement. For the other projects, the general assumption was that if a tillage system resulted in more surface residue cover and was economically sound, it would contribute to the SWEEP goals.

Planting and Fertilizer Applications

Two projects focused on the development and testing of new planting or fertilizer application equipment for conservation tillage systems. In one of these studies (Appendix E.3.4), the researchers endeavoured to develop a fertilizer placement machine for use with dry urea N that would perform as well as the liquid 28% N applicators commonly used in conservation farming. It was believed that some farmers would be more willing to convert to a no-till or minimum till system if they could use dry fertilizer. A machine was developed that could be pulled in tandem with the planter, and would apply fertilizer a precise distance below and to the side of the seed. Some difficulties were experienced with the machine in the first year of the study, but by the second year, corn yields on the dry fertilized plots were as good or better than yields from the liquid fertilizer plots.

It is expected that this machine would appeal to only a small portion of the farmers who practice, or are considering converting to a conservation tillage system. Farmers who live in areas where liquid fertilizer is difficult or expensive to acquire, or those who do not want to buy the storage equipment for liquid fertilizer may be very interested in this dry fertilizer applicator machine.

In the other equipment development project, cross-slot planter openers were imported from New Zealand and installed on a White-New Idea® air planter (SWEEP Report No. 42). The cross-slot planter had shown considerable promise in no-till systems in New Zealand and in the United States. The planter places liquid fertilizer slightly below and on the opposite side of the planter slot from the seed. Due to delays in receiving the equipment from New Zealand, it was only possible to test the performance of the cross-slot planter in the 1991 field season.

The cross-slot planter was compared with two other modified planters (Appendix E.3.6). One of the planters used the strip band system, applying fertilizer in two strips on either side and slightly below the seed. The other planter used the coulter strip system, applying the fertilizer at the front edge of a fluted coulter where it received a certain amount of incorporation with soil before seed placement. All three fertilizer application systems were still at the experimental stage. They were compared with each other and with a conventional planter/fertilizer applicator.

The cross-slot planter had yields comparable to the strip band planter. The researchers acknowledged that, although some additional fine-tuning was required to achieve optimum performance from the cross-slot planter, it appeared to be a promising development. The coulter-strip fertilizer application system had some problems with the hard soil conditions at planting time. As a result, the fertilizer was only mixed in the upper 2-3 cm of soil. Despite these problems, at the one site where it was tested, the coulter-strip system test plots had good, but not significantly better yields than either the cross-slot or strip-band planter plots. The cross slot planter was considered to have potential advantages in that it places P and the seed on opposite sides of the furrow, avoids the effect of drying of the seed furrow on germination, and avoids exposing seedlings to any smearing of the walls of the seed furrow.

The results from this TED project were not conclusive. It would take several plot years of research to determine which, if any, of the planters was superior under all conditions. However, the project provided the researchers and several innovative farmer cooperators with an opportunity to test several promising new no-till planter/fertilizer application developments under Ontario conditions.

In another TED study, five farmers in Kent County compared their conventional planters against a Tye® Drill set at a narrow row spacing (Appendix E.3.5). The farmers had hoped to eliminate the need for two separate planters; one to plant soybeans and one to plant small grains. A number of different coulter and presswheel combinations were tested with the Tye® drill. The results of the study were not encouraging. At all but one site, soybean yields from the planters were greater than for any of the Tye® drill treatments. The farmers believed that

further minor adjustments to the drill might improve its performance, but overall, the Tye® drill did not meet their expectations.

PRIMARY TILLAGE

One low cost equipment modification that showed some promise as a soil conservation measure was the cut-off moldboard plow. Fall plowing is considered a necessity by many farmers, especially on heavier textured soils and in wet fall conditions. Earlier research had shown pre-planting residue levels of 20% on fields where the modified moldboard plows had been used the previous fall. Two TED research studies were initiated to test the effectiveness of modified moldboard plows, one at the plot scale and one at the field scale (Appendix E.3.1). Three different cuts of increasing severity were tested on both European and American plows on corn residue.

The results from both studies were similar. Usually the plow that was cut-off the most left the greatest amount of surface residue, but often the resulting soil surface after plowing with the cut-off moldboard was considered unacceptably rough. In the plot scale studies, none of the treatments achieved 20% or more residue cover after spring runoff. In the field scale studies that followed, the cut-off moldboard plow achieved residue levels of more than 20% at two of the four sites. However, the residue levels on the full (uncut) moldboard treatments were also high at three of the four sites, in some cases higher than the cut-off moldboard plow treatments. There were no consistent significant differences in soybean plant growth or yield among the treatments at the different sites.

The modified moldboard plow may be a low cost and low risk "first step" towards adopting a conservation tillage system. Some farmers may prefer to use this tillage modification and continue with their other farming operations as usual. With time and fine-tuning of the equipment, consistently high residue levels may be achievable with this system.

SUBSOILING

Two TED studies were conducted to assess the benefits of subsoiling on soil properties, infiltration, water movement, and subsequent crop yields (Appendix E.3.2). In the first study the subsoiling took place in June, between the corn rows. In the other study, subsoiling took place in the fall, after wheat harvest. The farmers involved in the study believed that they had a compaction problem, and were interested in testing some different subsoilers on their farms.

The timing of the subsoiling operation proved to be critical, especially in dry years. The June subsoiling in 1988 at a shallow depth (18 cm) proved detrimental to the growing corn crop, as the plants were more vulnerable to the drought which occurred that summer. Deep subsoiling (31 cm) resulted in improved crop yields, particularly on the severely compacted soils. Had the early season subsoiling not been followed by a drought, the results may have been different. Subsoiling in the fall resulted in improved soil structure but yield increases were recorded at only two of the fourteen sites. This was not unexpected, since only a few of the sites were rated as severely compacted.

Overall, the TED studies did not come out in favour of subsoiling. It will not likely be cost effective unless a severe compaction problem exists. This underlines the need for a suitable method for a farmer to identify whether a severe compaction problem exists, and where remediation will produce a favourable response. Where possible, farmers would be better off avoiding the activities which cause compaction, such as operating heavy machinery on wet soils, and reducing compaction by incorporating deep rooted crops into the normal crop rotation. These measures may prevent the need for subsoiling.

RESIDUE MANAGEMENT

A wide range of residue clearing attachments for a no-till planter were compared in a two year study on zone tillage systems, where the crop residue is moved from the row area during seeding (Appendix E.3.7). The systems and modifications tested included a slot planting system, disk furrowers (one and two), wire brushes, spoked wheels and fluted coulters with and without the addition of brushes, spokes, furrowers or a V sweep. A conventional (moldboard plowed) treatment was used as the control planting system. The main purpose of this research was to evaluate some of the wide range of residue clearing devices that are available, in terms of their effect on seedbed conditions and yield.

It was concluded that wire brushes and passive V sweeps were not effective for removing corn residue, and would be better suited to moving soybean residue or residues that were not anchored. None of the other modifications or devices proved to be superior under all conditions. Yields from the control treatment tended to be greater (but not significantly) than yields from any of the zone tilled treatments. The information gained in the study could be helpful for farmers who want to modify their present planting system.

A study on the management of mulch tillage systems for clay soils compared offset disk and chisel plow tillage with moldboard plow tillage (Appendix E.3.8). The tillage was conducted on both soybean and corn residue and under both wet and dry soil conditions. While most of the mulch tillage systems provided adequate residue cover after corn (in the 30 to 50% range), the physical condition

of the soil was considered inferior to the moldboard plowed treatments. Mulch tillage resulted in more favourable soil conditions and better corn yield when the previous crop was soybeans, but residue cover was not adequate for erosion control. This finding led the researchers to recommend no fall tillage following soybeans, and only minimal spring tillage.

Rainfall simulations were conducted shortly after planting on four of the corn residue treatments at one of the two mulch tillage research sites (SWEEP Report No. 54). Residue cover on the mulch tillage and zero-tillage treatments ranged from 19 to 28%, while the moldboard plowed treatment had a residue cover of 5%. The mulch tillage and zero tillage treatments all generated less runoff, and had significantly less soil loss and sediment phosphorus loss than the moldboard plowed treatment. The increased amount of residue cover on the mulch tillage treatments appeared to be effective in reducing soil and phosphorus losses.

Extension Booklet

One TED contract resulted in the publication of a booklet by OMAF, entitled "Equipment Modifications and Practical Tips for Use." This publication contained photographs and descriptions of a wide range of modifications to moldboard plows, chisel plows, tandem disks, conservation seed drills, row crop planters and ridge-till systems. The discussion about each system also included a note about field conditions where the machinery had proven to be useful, and a list of practical tips for getting the best results from the implement.

Summary

One of the goals of the Technology Evaluation and Development (TED) subprogram of SWEEP was to involve the farming community in the process of developing technologies and management systems. Innovative farmers are constantly on the lookout for new and improved machinery, and they are probably the best judges as to whether a machinery development is useful. With few exceptions, TED research projects that looked at different tillage options required a large amount of farmer participation. Many of the farmers gained an understanding and appreciation (and no doubt some frustration) of the efforts of the researchers to scientifically validate the results of the different experiments. It is hoped that the experience of working on the TED research projects will encourage farmers to initiate and participate in future agricultural research studies.

5.4 Fertility Management

Soil conservation practices which leave crop residues on the soil surface or shallowly incorporated or which introduce cover crops into the system, may alter soil fertility and plant nutrient relations. The surface of the soil, being the source of much of the water-borne sediment, and the enrichment of these sediments with P have a direct bearing on P-loading from agricultural cropland.

The TED five year plan listed expected results from research including:

- data on the nutrient distribution in soils under conservation farm management versus conventional, and the implications of nutrient distribution for crop growth, management, and efficiency of soil fertility;
- data on erosion, P movement, and associated problems related to manure management;
- use of anhydrous ammonia and P enrichment of surface soils under conservation farming;
- improved fertilizer placement equipment;
- recommendations for farmers regarding the costs and benefits associated with more accurate fertilizer placement and requirements for phasing in components of conservation farming.

Understanding the implication of the stratification of phosphorus in systems which do not allow for soil incorporation was considered a high priority for research in TED. Appropriate fertilizer placement in conservation systems was linked to some extent with this concern for optimum nutrient positioning in the soil.

The most efficient use of manure nutrients and environmental guidelines strongly suggest that manure should be well incorporated into the soil. This would seem to reduce the conservation farming options for livestock farmers. Therefore the development of strategies combining manure management with soil conserving farm management was considered a high priority for research. Technical difficulties were encountered in designing experiments to evaluate manure management practices under TED. Therefore, this work was delayed until relatively late in the TED program.

NUTRIENT STRATIFICATION

A survey of fields verified the existence of stratification of organic matter and soil test P, K, Mg and Ca according to the relative degree of soil incorporation by tillage (Appendix E.4.6). Lack of soil mixing resulted in an accumulation of nutrients at or near the soil surface.

Vertical stratification was least pronounced on sandy soils where nutrients were believed to leach more readily through the soil profile. Horizontal stratification was evident particularly as the number of years a field was in no-till increased. The findings were not linked with evidence of problems of soil sampling or nutrient availability in the reduced and zero-tillage systems. No changes in farm management practices that related to the findings were proposed.

PHOSPHORUS

A study dealing with phosphorus placement in no-till concluded that fertilizer recommendations based on the OMAF soil test were adequate (Appendix E.3.6). In this study at 7 sites, there was no response to fertilizer P in excess of that recommended. In addition, the recommended rate was the most profitable.

Alternative phosphorus placements were studied to develop superior placement and more efficient use of P on no-till corn planters, possibly reducing excessive soil enrichment of P. A strip band application (2 strips on either side of the row, 2 cm below seed) was marginally superior to a side band (conventional, 5 cm to side, 5 cm below) but the difference was not considered great enough to warrant the planter modifications that are necessary. The coulter strip (fertilizer applied to soil surface in front of a fluted coulter) method was not well tested under the experimental conditions but there was some indication that it did not provide adequate soil mixing. The cross slot planter method was considered to have potential advantages as discussed in Section 4.3 (Tillage Options).

NITROGEN

Farmer interest in the merits of split applications of nitrogen and the proportion of the total N in each application prompted field trials (Appendix E.4.1). Although it was proposed that crop residues in conservation tillage systems might require more N at planting than conventional systems, data were not obtained to support this theory. No benefit was attributed to splitting the nitrogen application. However, further testing is warranted because the anticipated benefit may be related to the level of soil N, a factor which may now be measured with the new soil test.

In studies which documented the fate of nitrogen in corn systems on a lowland clay soil, fertilizer nitrogen use efficiency was generally similar for conventional, zero-tillage, and ridge tillage (Appendix E.4.3). Nitrate losses from surface and subsurface runoff were between 9 and 13% of the fertilizer added. Conventional tillage had the greatest cumulative nitrate losses and the greatest volume of subsurface (tile) flow which was thought to be partially due to soil cracking. Ridge tillage had the greatest volume of surface flow. Subsurface flow always exceeded surface flow by a factor of approximately 2 to 4. The impact of management on altering both the flow of water and the amount of mobile nitrate-N in the system was demonstrated by examining sod compared to tillage systems for corn. A bluegrass sod was very effective in producing the least surface and subsurface flow volume whose nitrate concentrations were well below those of the corn system.

This research suggested that cover crops, intercrops, or controlled drainage might contribute to the reduction in nitrate concentration in tile waters in corn production systems. Most importantly, there was little evidence that the soil management practices instituted to reduce P-loadings pose any increased risk to the environment from N pollution.

Further research explored the question of whether cover crops can indeed reduce nitrates in tile waters. Studies were carried out to examine the ability of cover crops to scavenge excess nitrogen by picking it up in the fall and carrying it over into spring (Appendix E.4.2). The researchers were unable to successfully establish cover crops in a high yielding corn system, although they were established successfully in, and after, winter wheat and spring barley. High nitrogen fertilizer rates applied to the cereal crops did not consistently influence the biomass production of the cover crops of oilseed radish, red clover, and annual ryegrass.

All cover crops initially reduced soil nitrate levels in the fall relative to those plots without cover crops, with reductions in the vicinity of 10 to 15 kg mineral-N/ha in September. By November, however, where there had been no cover crop, the soil nitrates were often the lowest. There was a tendency for ryegrass to sustain lower mineral nitrogen levels than red clover or oilseed radish.

Nitrates were released in early spring from oilseed radish with levels of approximately 50-60 kg/ha of mineral N. A portion of this nitrogen was considered to be lost by June and unavailable to the succeeding corn crop. Red clover provided residual nitrogen to corn, with values from 95-160 kg/ha mineral nitrogen detected in a June sampling of the soil. Oilseed radish provided some mineral nitrogen as detected by the increase in seedling corn weight early in the season where no additional N was supplied relative to a control. Ryegrass caused an overall decrease in available N resulting in the lowest yields for unfertilized corn.

In two rainfall events simulated under laboratory conditions, 5 to 10% of N, and 20 to 33% of P in cover crop residues, was measured in the leachate. Red clover leached the smallest proportion of the total nutrients contained in its biomass. Relatively greater amounts of P were leached from oilseed radish than from other residues.

These findings are based on one year of research. This research area is a high priority for further work to understand the role of cover crops in nutrient cycling. In particular, in systems in which nutrient excesses are much greater than here, such as where manure is used, cover crops may have a more significant role in the prevention of leaching and runoff losses of nitrates.

MANURE MANAGEMENT

Conservation farming systems using manure were developed for testing in TED on the basis that cover crops are effective in retaining the nutrients from manure and providing soil surface cover to minimize soil erosion. Growing a 'catch crop' following manure application allows the manure to be incorporated since the cover crop replaces the soil cover which is lost through tillage. On the other hand, when manure is applied with little or no incorporation on a reduced tillage system or onto a growing crop, the runoff inhibiting effects of the high levels of surface residue may be sufficient to prevent the loss of nutrients (Appendix E.4.4).

Fall Application Following Winter Wheat Harvest

Manure applied following winter wheat harvest was incorporated with a cultivator or disc. This allowed for high residue levels in the absence of additional crops or tillage. An oilseed radish crop planted after this manure incorporation provided a complete soil cover by fall, which was barely reduced even after fall chisel plowing. Also, in the fall, soil nitrates were lower where oilseed radish had been grown than where it was not grown, indicating that it may have prevented nitrogen from leaching. Manure application the following spring appeared advantageous to corn yields compared with the application the previous summer. However, this effect was eliminated by application of nitrogen fertilizer. This might indicate a suitable management to be a split application - one in summer following winter wheat harvest, and another the following spring pre- or post-emergent corn. On a silt loam soil there appeared to be an advantage to corn yields from increasing the amount of tillage from zero and aerway tillage to chisel or moldboard plowing. This was not true at the sandy loam site.

Spring Application to Winter Wheat

Application of manure to winter wheat in late April should provide nutrients which may be taken up by the growing crop and prevented from leaching. Winter wheat established no-till into soybeans the previous fall would provide sufficient soil cover to prevent runoff. In fact, regardless of the method of establishment of the winter wheat, ground cover at the time of manure application was high, ranging from 52% to 92%. Fertilizer and liquid manure at high rates did not improve wheat yields above low rates. However, lower rates of fertilizer and manure tended to favour red clover growth over the higher rates. Mature compost addition had no effect on winter wheat yields. Immature compost improved yields slightly compared with no N additions and it did not reduce red clover growth or stimulate fall weeds.

Mid Summer Application to Established Forage

An alfalfa hay stand offered an application site for manure with a full ground cover, following the first cut of hay. This practice is not uncommon where manure is irrigated onto previously harvested hay fields. In the first year of this study, neither solid manure nor compost applications affected forage yield or composition. The first cut the following year showed forage yields were improved by manure or compost, which increased the grass component of the stand. Following a second application of manure or compost, the second and third cuts showed no yield response. Soil nutrients were depleted over the study period.

Fall Application to Rye

In a soybean system, manure can be incorporated prior to fall seeding of rye. The following spring soybeans are drilled into standing rye and the rye is mowed to form a mulch.

Under this system the rye provided suitable ground cover in the fall provided it was seeded earlier (late August) rather than later (late September). The timing of rye planting had a greater effect on its production than the manure application.

The presence of rye, with or without manure, reduced soybean plant weights. The solid manure used in this study did not overcome the nutrient deficiencies created by growing soybeans in rye mulch. It is speculated that greater success could be achieved in a system using liquid manure.

In the Cropping Strategies section of this report, it is suggested that the rye no-till soybean system might be most acceptable in a livestock system where the rye is harvested or grazed as forage, instead of mulched (Appendix E.2.3). In another study (Appendix E.2.4) the rye mulch-soybean system was successful. This may be attributed to the sandier soil type in the latter experiments.

SUMMARY

The confirmation that vertical nutrient stratification exists in systems in which tillage does not mix or shallowly

mixes fertilizer with the soil was expected. There is no indication that this would be of concern to farm management in terms of application rates and soil testing methods. The TED work did not indicate that increased phosphorus contribution from these fields is likely.

Further, nitrogen losses from conventional, ridge tillage, and zero tillage corn in runoff and tile drainage were similar and there was no indication that conservation practices would lead to greater pollution of nitrogen in waters. A sod crop dramatically reduced nitrogen losses and nitrogen concentrations in runoff and tile waters relative to any of these corn systems, however, which would suggest that cover crops or intercrops may play a role in reducing nitrate leaching from soils.

In research which examined this possibility, it was found that cover crops of ryegrass, oilseed radish, and red clover, scavenged nitrogen initially but that soil nitrate levels were often as high or higher under the cover crops during the late fall and winter. The pattern of release of the nitrogen differed widely among the cover crops with some (oilseed radish) releasing too early to be largely available to a corn crop while others immobilized nitrogen to the extent of depressing corn growth early in the season in the absence of supplemental nitrogen. There seems a need to more clearly understand the contribution of cover crops in nutrient cycling.

There was some evidence from this same study that the various cover crops are leached of their nutrients to varying degrees by rainfall. The question of the importance of residues in contributing to soluble P levels was raised and is discussed in Section 5.7.

The manure management studies in TED provided useful agronomic information and tested some interesting and environmentally viable systems for manure applications. The design, timeframe and budget of the manure studies did not allow for full evaluation of the environmental implications of the management. In some cases the manure was not incorporated, such as the applications to established forages and to winter wheat in the spring. These systems have the advantage of providing high ground covers of 50 to 100% which could be expected to minimize runoff and soil erosion.

Other management systems, such as manure applications following winter wheat harvest and soybeans, provide opportunities for manure incorporation. When incorporation is accomplished by tillage which does not involve full soil inversion by moldboard plowing, the main crop residue may provide sufficient cover to reduce soil erosion. Some tillage was shown to be required to maximize corn yields the following year in these studies. Cover crops appear an option for providing ground cover following the incorporation of manure. In the case of a rye cover crop, advantages to the system are in providing livestock forage prior to spring planting of soybeans.

Further studies are required to fully understand the environmental impacts of the use of manure in reduced tillage and where there is no incorporation of the manure.

5.5 Pest Control

A lack of understanding of weed control in systems in which tillage is reduced or eliminated was considered a significant barrier to the adoption of these systems, particularly in the earlier years of the SWEEP and other soil conservation programs.

The TED five year plan identified several results to be expected from research in this area:

- the development of a cost effective, efficient, and practical series of weed management techniques which will provide farmers with the tools to deal with the unique weed problems which occur under various forms of conservation farming;
- data on the problem weed species common to forms of conservation tillage in various regions and the relative impacts of these species on yield and crop management;
- the development of a methodology for integrating various types of weed control into an effective control strategy for individual farm management systems.

Some early perceptions were that reduction in tillage would lead to higher herbicide use - an undesirable approach from both an economic and environmental standpoint. TED research has shown that this is not necessarily the case. Herbicide use changes but the volume of herbicide used need not increase.

The development of cost effective, efficient, and practical weed management techniques was rated as a high priority in the research program. Results of the farm survey in 1988 affirmed this priority research area, as 36% of the farmers ranked weed control and herbicide research as the #1 priority. Farmers expressed concerns about the availability, efficacy and mixes of herbicides to control weeds in conservation farming.

Weed Survey

An extensive weed survey related tillage and crop systems and years in the system to the weed spectrum in fields throughout the counties of southwestern Ontario (Appendix E.5.1).

Survey results indicated that conservation and no-till systems had qualitatively similar weed communities as in conventional tillage systems. The reduction in tillage did not necessarily lead to more difficult weed problems. Weed communities were highly variable in all tillage systems.

Timing of weed emergence was similar for most species, regardless of tillage used. Some annual weeds were slower to emerge in no-till than in conventional tillage. Growth rates and reproduction timing did not differ. No-till fields tended towards a more uniform development of perennial weeds than conventional fields which may actually result in improved control with herbicides.

At the time of the survey in 1988-89, no-till farm systems used slightly more herbicides overall. They were also more likely to use chemical burndowns and spot treatments, but less likely to use soil incorporated herbicides.

There was no evidence to suggest reduced effectiveness of herbicides in reduced tillage systems.

HERBICIDES

Throughout the period of 1987 through 1990, extensive experiments were ongoing to develop weed control recommendations for farmers using conservation tillage system. It was confirmed that effective weed control was possible in soil conservation systems without higher herbicide dosages. The TED report on this research (Appendix E.5.2) provides an extensive set of recommendations for cereal and legume burndown plus residual weed control where corn or soybeans follow. Herbicide antagonism was evaluated and tank mixes recommended. In addition, tank mixes and additives were evaluated for their effectiveness. Currently registered herbicides at labelled rates provided satisfactory weed control regardless of the tillage system.

TILLAGE

Physical effects of tillage were examined under greenhouse conditions (Appendix E.5.1). Burial as might be accomplished by soil inversion from plowing decreased survival of seeds of perennials but not annuals. However, vegetative propagules of perennial roots or rhizomes survived better when buried than when left on the soil surface. While actively growing annual weeds were vulnerable to damage by cultivation at all growth stages, actively growing perennials were susceptible to control by tillage over relatively short time periods. Wounding by shallow cutting caused a greater reduction in the biomass of surviving annual plants than either deep cutting or soil inversion.

WEED SUPPRESSION

Cover crop research (Appendix E.2.3) suggested that cover crops can effectively suppress particular weeds. Ryegrass in corn suppressed late flushes of annual weeds and fall growth of quackgrass. In winter wheat, interseeded legumes resulted in there being fewer weed seeds in the soil in the fall. The weed control was dependent on high levels of biomass production of these cover crops.

A fall rye mulch reduced weeds in soybeans. This was believed to be a result of the rye depleting soil nitrogen, and the physical effect of the mulch affecting soil properties such as temperature. In such a system, the main crop must establish and grow well in order to provide effective competition for any established weeds.

INTEGRATED WEED MANAGEMENT

The feasibility of an integrated weed management approach whereby reduced herbicide doses are band spray applied and shallow, inter-row cultivation is employed in a zero-till corn system, was studied over several years (Appendix E.5.3). The weed control provided was good to excellent using either pre- or post-emergent herbicides. Corn yields were unaffected and cost savings in herbicides were substantial. Two shallow, interrow cultivations seemed necessary. Weed escapes occurred mostly in the crop row. In the field trials, the farmer applied post-emergent herbicide, side-dress nitrogen application and cultivation with a heavy duty cultivator on each row of the crop, in one operation. A 30 cm herbicide band had been applied with the corn planter at planting for broad spectrum weed control.

WEED HISTORY

The weed survey confirmed that the weed history of the field was an important determinant of the weed pattern to be expected upon introduction of conservation tillage. The author of the study underlined the importance of regular weed scouting. It was suggested that advantages to no-till include the lack of burial of weed seeds and the reduction in the spread of quackgrass and other perennial species that spread by fragmentation (by tillage).

RISKS

Some understanding of the relation of tillage practices to herbicide transport was gained in a study conducted in a poorly drained soil in Essex County (Appendix E.6.4). Average transport of triazine in conventional, no-till and ridge tillage was 3-4% of that applied and of metolachlor was 2% of that applied. The persistence of these herbicides was found to be greater in conventional systems. In general, tillage and crop residues did not influence herbicide transport in surface and subsurface runoff since the proportion of rainfall appearing as runoff was similar among practices. However, tillage practices

which alter the hydrologic response of watersheds are expected to impact more on herbicide transport than tillage alone.

SUMMARY

Research carried out since 1987 in TED provided substantial evidence to reject the notion that reduced tillage systems lead to greater weed problems and higher herbicide dosages. Research was able to suggest that shallow inter-row cultivation is possible in a zero-till system without excess soil disturbance, or yield-reducing effects. It would suggest that this form of cultivation is a necessary step where band applications of herbicides are used.

An extensive survey was conducted of a wide range of farmers with differing experience in conservation systems and who were farming under different soil and climatic conditions using different conservation technologies. This study provided positive information that weed management need not be a problem under conservation tillage. The types of weeds faced by the farmer will change slightly as conservation tillage is implemented, however there are management tools readily available to deal with most of the problems. At the beginning of the TED program a very strong concern was expressed by the most experienced conservation farmers that weed management and the availability of appropriate products was, or could become a serious problem. By the end of the TED study it seems safe to conclude that their concern is significantly reduced.

In addition to the extensive weed survey which indicated that the shift from conventional conservation farming did not cause a major weed problem, several new practices and mixes of herbicides have been developed during the TED program. Work at the Ridgetown College of Agricultural Technology has resulted in a number of new mixes and rates of application using currently registered materials and uses which have proven to be extremely effective in controlling weeds at reasonable costs. The use of registered herbicides is significant because one of the major concerns of conservation farmers at the beginning of the TED program was the length of time which it took to have a new herbicide material or a new herbicide use registered in Canada. This administrative issue was not addressed by TED research, however, researchers under TED were careful to ensure that the herbicide mixes, rates and crop uses were strictly in accordance with registered practices.

Work done under TED by an innovative farmer, was able to demonstrate a 60% reduction in herbicide use through the integrated use of a herbicide banding and interrow cultivation. This reduction offers significant environmental and economic benefits, while at the same time appearing to have no adverse effect on weed pressures. The system was developed to the point where the inter-row cultivation was performed at the same time as nitrogen fertilization which meant no additional passes across the field. In effect, the secondary cultivation allowed the farmer to save 60% on his herbicide bill without substantially increasing the costs of his field operations.

At the beginning of the TED program a number of concerns were raised about the problems which might be encountered from slugs and armyworms if significantly increased crop residue was to be left in the fields. Throughout the three full seasons of research under TED no significant problems with either slugs or armyworms were reported, despite the fact that in many of the research plots, residue cover was in excess of 75%. However, the lack of slug problems may be attributed to the drier than normal conditions which generally prevailed during the three field seasons. The concern regarding an increase in slug, armyworm and other pest problems as conservation practices are more widely adopted may need to be addressed in the future.

A similar concern was expressed about the possibility of fusarium ear mould becoming more prevalent, especially with an increase in wheat stubble and corn residues left on the surface of the soil. This problem was discussed during the TED work term and is well noted, however no evidence that fusarium infections can be linked to the adoption of soil conservation practices has been found. No further action, other than to continue to monitor this situation, is recommended at this point.

5.6 WATER MANAGEMENT

The following goals for TED water management research were identified in the Background Paper and at the planning workshop:

- data on the costs and benefits of reshaping land for water management on low relief clay soils; and,
- data on the impact of various water management practices (reshaping, structures, cropping and tillage to increase infiltration) on P movement from cropped lands.

Five research contracts were initiated to address the above goals.

Four of the five water management studies involved extensive monitoring of surface water flow and, in two cases, subsurface drainage tile flow. These projects were expensive to initiate, due to the cost of purchasing and installing the equipment. In addition, contractors had to

visit the sites on a regular basis, and even more frequently during times of heavy precipitation. Despite the expenditures, some of the monitored sites produced very little useful data due to a shortage of the large rainfall events that were needed to produce runoff. At other sites, equipment failure, or extreme rainfall events which exceeded the capacity of the monitoring system resulted in lost data for part of the monitoring period. Thus, in most cases, the goals of the water management studies were only partially realized.

Structures

Many structural methods have been developed to provide erosion control, including grassed waterways, field terraces, water and sediment control basins (W.A.S.Co.B.'s) (sometimes called channel terraces), diversion terraces and emergency overflow spillways. A TED research project was initiated to develop an appropriate method for monitoring the effectiveness of a water and sediment control basin, in terms of its impact on sediment and phosphorus losses (Appendix E.6.1).

Several innovative methods were developed for monitoring the flow from the ponded area into the surface inlet, as well as measuring the amount of sediment that settled out in the ponded area. Unfortunately, during the monitoring period, very few rainfall events occurred at the site. Only one rain storm was large enough to generate runoff. Thus, the project resulted in what would seem to be an excellent method for monitoring a structural erosion control measure but very little data relating to sediment and phosphorus losses was obtained. From the information gained in the study, the researchers were able to conclude that the W.A.S.Co.B. could help to reduce the amount of sediment and phosphorus losses from cropped lands. However, a considerably longer research project covering many rainfall-runoff events would be required to evaluate the effectiveness of the W.A.S.Co.B. in the field.

Several hydrologic and soil erosion computer models were tested to determine if they could be used to estimate the effectiveness of the W.A.S.Co.B. for reducing sediment and phosphorus losses. The extent of the modelling work on this project was limited, as only one rainfall event was available for calibration and it provided only a partial set of data. However, the results from the modelling study were promising. This approach may prove to be a more reasonable and cost effective method of evaluating the potential of structural erosion control measures for reducing soil erosion and phosphorus losses from agricultural fields.

Surface Hydraulic Properties

Some tillage and farm management practices, such as cultivation, mulch tillage, residue management and cover crops, have the potential to increase the rates of infiltration and percolation into cropped lands, either through improved soil structure and macropore development or by preventing the formation of a surface crust. Increased infiltration could result in a reduction in surface runoff, and reduced soil and phosphorus losses from cropped areas. The effects of tillage and management systems on surface hydraulic properties were studied at the micro-scale in one TED project (Appendix E.6.2).

A portable device, the Guelph Pressure Infiltrometer (GPI), was used to compare the infiltration rates from soils under conventional and conservation tillage systems. The GPI provided rapid measurements of a number of soil hydraulic properties, including field saturated hydraulic conductivity and matric flux potential. Measurements with the GPI were not dependent on climatic inputs; thus, the project was not affected by the lack of rainfall events that hindered some of the other TED research projects.

At three of five sites no significant differences were found in the surface infiltration rates under the two systems. At two sites, soils under long-term no-till were observed to have lower field saturated hydraulic conductivity, lower total and macro-porosity and higher bulk density than either fall moldboard or chisel plowed soils and thus, no-till may result in increased surface runoff relative to fall moldboard plow or fall chisel plow tillage systems. Although the GPI does not measure soil or phosphorus losses, it was inferred that the increased risk of surface runoff from no-till soils could also result in greater losses of soluble phosphorus and other non-adsorbed chemicals. These increases may be offset by a decrease in soil particle detachment due to the effects of the increased residue cover on no-till fields.

Rainfall simulations were conducted in a separate contract on a large number of TED research sites (Appendix E.7.9). Although differences in surface hydraulic properties were not specifically examined, the response of different treatments to the simulated rainfall did show relative differences in surface infiltration rates. The results from the simulations were highly variable, but generally in agreement with those from the GPI study. In cases where a conservation management system resulted in increased surface runoff compared to a conventional system, losses of sediment and sediment bound phosphorus were still lower from the conservation system. There were exceptions, however. At some of the sites which were tested, such as the chemically versus mechanically (plow) killed cover crops, runoff, soil and phosphorus losses from the chemically killed (no-till) plots were significantly less than from the mechanically killed plots.

The susceptibility of soils under different management systems to runoff, erosion and phosphorus loss appeared to vary according to factors such as soil texture, field

slope, antecedent soil moisture, direction of tillage and the timing of tillage operations in relation to the rainfall event. Under natural conditions, the effects of rainfall intensity, duration and total accumulation on infiltration rates may be different for some management systems than for others, due to crusting, surface roughness and other factors.

Tillage Effects on Runoff; Uplands and Lowlands

Monitoring instruments were set up to measure the quantity and quality of surface runoff and subsurface tile flow under conventional and conservation management systems at two sites; one on an upland sandy loam soil in Huron County (Appendix E.6.3), and the other on a lowland clay soil in Essex County (Appendix E.6.4). The success of both of these projects was weather dependent, as only storms of a certain magnitude would result in runoff or tile flow.

At the upland site, surface and tile flow from a fall moldboard plow tillage system and a no-till system were monitored and compared. The monitoring equipment was installed on a productive farm, thus the barriers and flumes required to isolate and channel the surface runoff from the plots had to be frequently removed in order to permit timely field operations. Very little surface runoff occurred during the first 12 months of the monitoring period and as a result, surface runoff monitoring was discontinued before the completion of the study. It was concluded that the sandy loam soils at the site were not susceptible to surface runoff and erosion under either the no-till or fall plow systems. Rainfall simulations at high intensities were conducted (as part of an MOE contract) on both treatments, and showed greater amounts of runoff but less sediment and total phosphorus losses from the no-till soils. When rainfall simulations were conducted on a part of the field that had clay loam soils, both runoff volumes and soluble orthophosphate losses were greater from the no-till soils.

The amount of tile flow at the upland site was approximately equal for both tillage treatments. Samples of the tile water contained no appreciable amount of sediment or phosphorus, unlike the project on lowland clay soils where tile flow accounted for about 50% of the sediment and phosphorus losses. Nitrate losses through the tile system at the upland sandy loam site were of greater concern than sediment or phosphorus losses. The average nitrate level in the tile water from both treatments was 10.7 mg/L, which exceeded the drinking water quality limit of 10 mg/L. The high nitrate losses were attributed to rates of N fertilizer application, which exceeded the rate recommended by the nitrogen soil test.

At the lowland clay site, researchers monitored the quantity and quality of surface runoff and subsurface drainage flow from research plots under three farm management systems: conventional, ridge till and zero-till. The region had a sufficient number of major rain storms during the three year monitoring period to generate large volumes of both surface runoff and subsurface tile flow from the poorly drained, Brookston clay loam soil.

Residue cover immediately before planting averaged below 10% for the conventional treatment, and 88 and 95% for the ridge-till and zero-till treatments respectively. Samples from the surface runoff and the subsurface tile flow of all treatments contained significant amounts of sediment and phosphorus. As would be expected, the conventional (fall plow) treatment had the highest sediment losses, averaging 897 kg/ha over the three year period, compared to 530 and 391 kg/ha for the ridge-till and zero-till treatments respectively. However, the phosphorus content of the runoff from the conventional treatment was much lower than for either of the conservation systems. Thus, average phosphorus losses were the lowest from the conventional treatment. Tile drain flow accounted for from 42 to 68% of the sediment and phosphorus losses from all of the treatments.

The results from this study indicate that conservation tillage is not sufficient to reduce phosphorus losses from cropland located on lowland clay soils. Other measures may be necessary, such as optimizing phosphorus fertilizer use, controlling tile drainage flow and re-using the water (subsurface irrigation), creating wetlands, etc., to keep the nutrients in the fields. The technology and options for accomplishing this needs more work.

Land Planing

A three year study was conducted to investigate land planing on lowland clay soils in terms of the costs and benefits of the practice, and the impact on runoff, soil loss and phosphorus loss. Soils, crop yields and runoff quality and quantity were compared at a planed and unplaned site on four different farm sites, three located in Essex County and one in Kent County (Appendix E.6.5).

Land planing is one way of managing surface water on flat lowland clay soils. It can eliminate ponding of rainwater in low spots by creating a smooth, evenly graded surface. Traditionally, farmers have drained the low spots by cutting furrows into the field. The furrows remove part of the field from crop production, and can cause inconveniences in field operations. Thus, there was considerable interest in evaluating land planing as an alternate method of water management. The environmental effects of land planing had not previously been investigated.

Despite some problems with obtaining accurate measurements of the amounts of runoff from the planed

and unplaned fields, the researchers were able to conclude that runoff, sediment and phosphorus losses from the planed fields were the same or possibly greater than from the unplaned fields. This finding is not surprising, since the low spots in the unplaned fields detain runoff, while runoff from the planed fields leaves the field as fast as the gradient permits. Any environmental benefits resulting from land planing would have to be the result of maintaining a uniform crop across the field, with no erosion prone bare spots caused by standing water on young crops.

Although some storms occurred during the study period that caused ponding over large parts of the field, the crops on the planed fields did not fare any better than those on the unplaned fields. No significant yield differences were noted between planed and unplaned fields. Thus, the cost of land planing (estimated at $260 to $790 per hectare) was not recovered through improved yields during the study period. Results could have been different, depending on the timing of the excess rainfall and the value of the crop grown. The benefit of land planing may also come from the land extensive farming operations it makes possible. Large field sizes and large equipment may result in economics of scale which allow the farmer to recover the costs of land planing through reduced input and management costs. This is a farm-scale economic effect and was not tested during the TED study. However, it is clear that the farmers practising land planing have satisfied themselves that it is advantageous. However, from the results of this study, it would appear that land planing does not represent an economically or environmentally sound water management option.

5.7 PROBLEM UNDERSTANDING

The Five Year Plan identified a research category intended to:

- lead to an increased understanding of the basic processes which impact upon the objectives of TED research;
- provide the data required to enable decisions to be made on future research;
- develop research methods and tools to plan, monitor, and assess ongoing research.

ALLELOPATHY AND PHYTOTOXIC EFFECTS

Rated as a high priority was the examination of the nature, extent, and possible remedies to allelopathic and phytotoxic effects related to conservation farming and specific crop rotations. The University of Guelph undertook this research which consisted of three years of field and laboratory study (Appendix E.7.8).

The specific compounds studied were volatile fatty acids (VFA's) which are by products of biological fermentation, and phenolic acids which are organic compounds initially leached from crop residues. VFA's were not detected in field studies and were considered probably too volatile to be detected with the sampling methods employed. Further, corn did not consistently exhibit a yield reduction response to the presence of crop residues on the soil surface and hence the observation of farmers related to phytotoxicity could not be reproduced in research trials.

Residues had little effect on corn total emergence and final plant populations, but did result in some delays in growth stages of corn. Developmental delays were attributed to residue effects on depressing daytime soil temperatures and the accumulation of growing degree days. Slower emergence of corn, lower plant dry matter measured on particular dates early in the season, plus the presence of phenolic compounds, indicated that red clover residues may be phytotoxic to corn. Corn grain yields appeared most depressed when following grain corn. Phenolic compounds were, in fact, detected in the presence of several residues in one year and in the presence of all the residues tested, in another year. Concentrations of phenolics were sometimes reduced where crop residues were removed from the row area with trash whippers. Red clover and canola were identified as having possible allelopathic effects.

Laboratory studies produced VFA's and phenolic compounds particularly under wet and high temperature conditions. Fresh, green, or easily decomposable material was most likely to produce these compounds.

VFA's and phenolics applied in solution to corn and wheat seeds were found to affect germination and early growth at varying concentrations, and that the effect depended on the combinations of acids tested. Further, not all hybrids were affected similarly.

RESIDUE DECOMPOSITION AND P SOLUBILITY

Another study examined residue decomposition products and their effects on phosphorus solubility (Appendix E.7.3). The appearance of soluble carbon in the soil solution in the presence of residues, regardless of their placement in and on the soil, corresponded (at pH's <7.5) to responses of barley biomass, although the response related to either K or N content of the plant rather than P.

Incubated soils showed increased soluble total P and orthophosphate -P in addition to soluble organic carbon in the presence of alfalfa and corn residue. The source of the P is not clear, however, and is assumed to be either from release of mineral bound P, or from organic P. A third experiment demonstrated that in the presence of naturally occurring organic acids, applied phosphate reduced soil

retention of P. The implication is that crop residues which produced organic acids on decomposition, may be expected to affect release of soil bound P or decrease adsorption of applied P since the organic acids complex with the same sites on soil particles.

Soil Compaction

Research examining soil structural degradation and its relation to soil erosion, began with a pilot study survey to determine the extent of soil compaction on lowland clay soils in southern Ontario (Appendix E.7.1).

The survey results indicated that around 50 to 70% of clay to clay loam soils in Lambton, Middlesex, Kent, Essex, and Elgin Counties have some degree of subsoil compaction. Twenty five percent of these are considered to be severely compacted and to suffer from high yield reductions and soil erosion. Cropping practices and the use of equipment on wet soils were considered responsible for the soil conditions.

The pilot study led to research in several areas. Subsoiling of these lands found that it was generally not beneficial to crop yields, and may be of use only on severely compacted soils.

Since subsoil compaction is affected by soil moisture, decreasing field moisture content using subsurface drainage was believed to have potential for reducing compaction resulting from field operations. Lowering of the water table and the removal of excess soil water in a field is not uniform and depends on the spacing of tile drainage laterals. The study carried out in Essex County suggested that a moisture content of 20% was optimum for compaction of the Brookston clay (Appendix E.7.4). It was noted that at harvest time soils were generally below this level. Soil cracking during the summer months was considered to limit the wetting of the root zone during this period.

Soil Loss By Tillage Erosion

As a progression from studies carried out in TED and Tillage 2000 examining variability of fields and effects of landscape positions on soil loss (see Section 5.1 and Appendix E.1.2), research focused on shoulder slope erosion and the extent to which tillage operations move soil up and down slopes (Appendix E.7.5).

Results of tests with different implement types and operated at differing speeds indicated some relationship exists between the slope and tillage parameters but that the relationship was not consistent. Net soil loss downslope resulted from all tillage implements which included the moldboard plow, chisel plow, tandem disk and cultivator.

Anhydrous Ammonia

In meetings with experts following the TED planning workshop, the use of anhydrous ammonia was questioned as to its contribution to P movement through its effects on soil properties including structural degradation. A laboratory study (Appendix E.7.2) examined the contribution of anhydrous ammonia to structural degradation. In the ammonia retention zone wet aggregate stability and microbial activity initially decreased. This decrease was accompanied by an increase in levels of water soluble organic carbon and sometimes the dispersion of clay from soil aggregates. Over a 112 day period the Brookston clay soil continued to show a declining aggregate stability and soluble organic carbon levels of 200-400 mg kg^{-1}. In the absence of leaching of this C, microbial activity in the zone resumes, and is accompanied by increases in aggregate stability and conversion of soluble organic C by organisms. The impact of the anhydrous application was considered to be not significant in soil quality deterioration at the field level.

Agroecosystems

A final area of research characterized agricultural ecosystems in terms of microfloral and faunal populations and their relation to soil properties and decomposition of residues (Appendix E.7.6). Comparisons were made between agricultural and non agricultural systems.

Earthworm numbers were greater (2 times) in a long term pasture versus zero tillage. On disturbance of these systems by plowing, earthworms did not recover within one sampling season. Plowing disturbance did not affect soil microbial biomass levels over the season. Return times of microbial biomass, nematodes, slugs, and sowbugs, which play a role in decomposition, were greater after plowing a zero till soil than a pasture soil.

In another related study (Appendix E.7.7), the effect of distance from woodlot into an agricultural field on distribution of invertebrates was examined. There were fewer cryptozoa numbers as distance from the woodlot increased. Slugs and millipedes were concentrated near the woodlots. Crop residues in the field offered protection in a chisel plow system, resulting in greater numbers of invertebrates at every distance from the woodlot. Crop residues also promoted dominance of several taxa during particular times of the year. The implication of this was decreased natural predator control of pests in large agricultural fields (more areas of greater distance from the woodlot) and possibly interference with decomposition and nutrient cycling.

Summary

Many of the farmers with the longest history of conservation technology experience who contributed to the planning of TED identified yield reduction effects from

crop residues as a major concern. The yield has been observed to vary significantly, especially in fields where winter wheat has been grown. This problem was perceived to be significant enough to make many farmers question the use of winter wheat and the use of cover crops in their rotations. The early work in TED in this subject area, focused on finding chemical components to which the yield reduction effects could be attributed. Subsequent work followed up on the possibility that much of the yield reduction could be explained by temperature impacts of soil residue cover. Additional work focused on the role of a carbon source in controlling the chemical reactions which might result in phytotoxic chemicals.

Volatile fatty acids were identified as one of the possible yield reducing compounds. Laboratory studies supported this possibility. However, field studies did not detect the presence of VFAs in fields where yield reductions were experienced. It may be that the volatile nature of the chemicals prevented their detection in the field. The volatile nature of these compounds may also explain why the use of trash whippers was found to alleviate the yield reduction problems. The aeration caused by the disturbance of residue over the rows may have been adequate to volatilize the compounds and reduce their impact, or provide oxygen to stimulate the activity of residue-decomposing organisms. However, it can also be hypothesized, with equally strong supporting data, that the removal of residue cover from the row has resulted in temperature changes which have alleviated the yield reduction.

Extensive TED research served to identify some of the important parameters in the complex process which appears to result in yield reductions due to crop residues. These parameters include the biological activity in soil and crop residues, the moisture and aeration levels, as well as the quality and quantity of the carbon source. Soil temperature may also be both an agent of yield reductions, as well as a driving force behind the chemical reactions which result in the production of volatile phytotoxic compounds. The work suggests that the process shares some similarities with the nitrogen cycle. Different compounds are involved but these compounds appear to be extremely volatile. The conclusion of the TED research is that, while we do not yet have the answers to the cause of yield reductions due to crop residues, the problem is apparently not as large as originally thought. The effects are real and have been observed in the laboratory and in the field. However, it appears that the risks are intermittent and relatively small-scale and may be managed using modifications to the farming systems when planting into heavy crop residues. This statement is tempered with the note that research failed to replicate farmer experience in the field in terms of yield reduction effects related to crop residues.

Continued studies integrating the disciplines of soil microbiology, soil chemistry, soil physics and the impact of soil management on these properties is required.

6. DISCUSSION

This section of the report is a discussion which integrates the results of the individual components of the TED research program and relates them to the main TED program objectives: reduced soil erosion; reduced P loss from cropland; and long term soil productivity and quality.

6.1 SOIL EROSION

6.1.1 SOIL EROSION - THE BACKGROUND

Soil loss from agricultural land is a process which reduces the productivity of cropland and degrades the quality of water. This process results in economic losses for individual farmers and society at large. Evaluating and developing farming practices which will reduce soil loss was a major part of the TED mandate.

The process of soil loss includes detachment and transport of soil particles. Detachment is caused by inadequate control of raindrop impact or inadequate protection from wind. Susceptible soils are characterized by poor surface structure and/or lack of surface protection. The primary method of soil transport is by overland flow of water. Overland flow is caused by: (i) poor infiltration associated with frozen subsoil, surface crusting, and/or subsurface compaction; (ii) poor subsurface drainage due to naturally impervious subsoils or subsoils which have been rendered impervious by man; and (iii) concentration of flow associated with uncontrolled runoff and sloping topography. Transport of soil by wind is a significant problem on some sandy soils, and some organic soils and is related to inadequate soil cover, the removal of fencerows and other windbreaks, and excessive secondary tillage (from background paper). A consensus was reached at the planning workshop that the impact of wind erosion on the SWEEP-TED objectives was not well understood and could not be profitably addressed in the research.

Measures which reduce the velocity and/or the concentration of runoff will reduce the erosive power of the water. Cropping and tillage practices that increase the quantity, quality, duration, or timeliness of ground cover can effectively reduce the erosive force of surface flow. Water control structures can retain surface flow, decrease slope length, or concentrate flow into protected channels. The ability of water to flow into the soil is determined by soil texture, soil structure, and topography.

The impact of agricultural practices on soil loss can be examined from several perspectives:

i) effects on soil cover quantity, quality, and timeliness;

ii) effects on soil structure and hence, infiltration and permeability; and,

iii) effects on soil retention by water control structures (from literature review, Appendix G).

The following review of relevant literature discusses the issue of soil loss in terms of current knowledge in the three areas listed above. Similarly, much of the research in TED is able to address soil loss issues from at least one of these soil loss perspectives.

Detachment requires energy provided by falling raindrops and flowing water (Wischmeier and Smith 1965 in lit.rev). The amount of detachment which occurs is related to the extent to which the soil is protected from raindrop impact. A crop canopy's ability to prevent detachment is inversely related to its height above the soil surface (USDA, 1978 in lit.rev.) For example, a full covering of mulch at the soil surface is estimated to reduce erosion by 95%, while a canopy 4 metres from the soil surface and with an 80% cover, may reduce erosion by only 20%.

Raindrop impact causes the breakdown of soil aggregates, with the possible outcome of puddling and sealing the soil surface, thereby increasing overland flow of water. When the infiltration rate plus surface detention is exceeded by rainfall, excess water runs off, transporting soil particles (Begg, 1982, and Wischmeier and Smith 1965 in lit rev.). Thus, soil transport is associated with poor infiltration, poor subsurface drainage, and concentration of flow by sloping topography.

Long term annual soil loss (A) is described by the USLE (Universal Soil Loss Equation) in which A is a function of R (rainfall and runoff factor), K (soil erodibility), LS (slope length and steepness), C (cover management), and P (control practices). Hence, soil loss is a function of both rainfall and soil/landscape parameters.

The USLE's rainfall and runoff factor (R) takes into account the rainfall energy-intensity. "The energy of a rainstorm is a function of the amount of rain and of all the storm's component intensities " and, "...when factors other than rainfall are held constant, storm soil losses from cultivated fields are directly proportional to a rainstorm parameter identified by [R]" (Wischmeier and Smith 1978).

The proportional monthly distribution of R is depicted in Figure 8. In southwestern Ontario, peak rainfall energy-intensities occur in the summer months while the lowest levels occur generally in December-March.

Soil erodibility, the USLE's K-factor, reflects difference in inherent soil properties which cause some soil to erode more readily than others (Wischmeier and Smith, 1978). K values are obtained from tables which represent an average for that soil as determined under varying antecedent moisture and rainstorm conditions. Particle size distribution and organic matter are indicators of erodibility.

Greater detachment and transport were observed after rainfall and /or snowmelt on soils having frozen (impervious) subsoils which was reflected in the seasonal variation in soil erodibility (Dickinson and Pall 1982 in literature review).

Computed values of seasonal erodibility (Ks) were highest in the winter spring thaw period (March), determined in field measurements. Ks values decreased in the spring and summer and were lowest in the fall (Wall et al., 1988). The authors note that during the winter spring period erosivity is low while the susceptibility to erosion is relatively high.

Cover management effects are described by one factor (C), since tillage, cropping and rotation management factors interact to produce an effect. The soil surface protection afforded by the crop canopy depends on the type of vegetation, stand, and quality of growth, which will vary throughout the season. The effectiveness of crop and management factors will depend on the surface protection coinciding with the time when erosive rain occurs. The C-value for a particular system differs to reflect the coincidence (or lack of) soil cover and expectancy of highly erosive rainfall. Soil cover described by the C factor includes both canopy and mulch. Mulches intercept falling raindrops near the surface so that the drops regain no fall velocity. They also obstruct runoff flow thereby reducing its velocity and transport capacity. (Wischmeier and Smith, 1978)

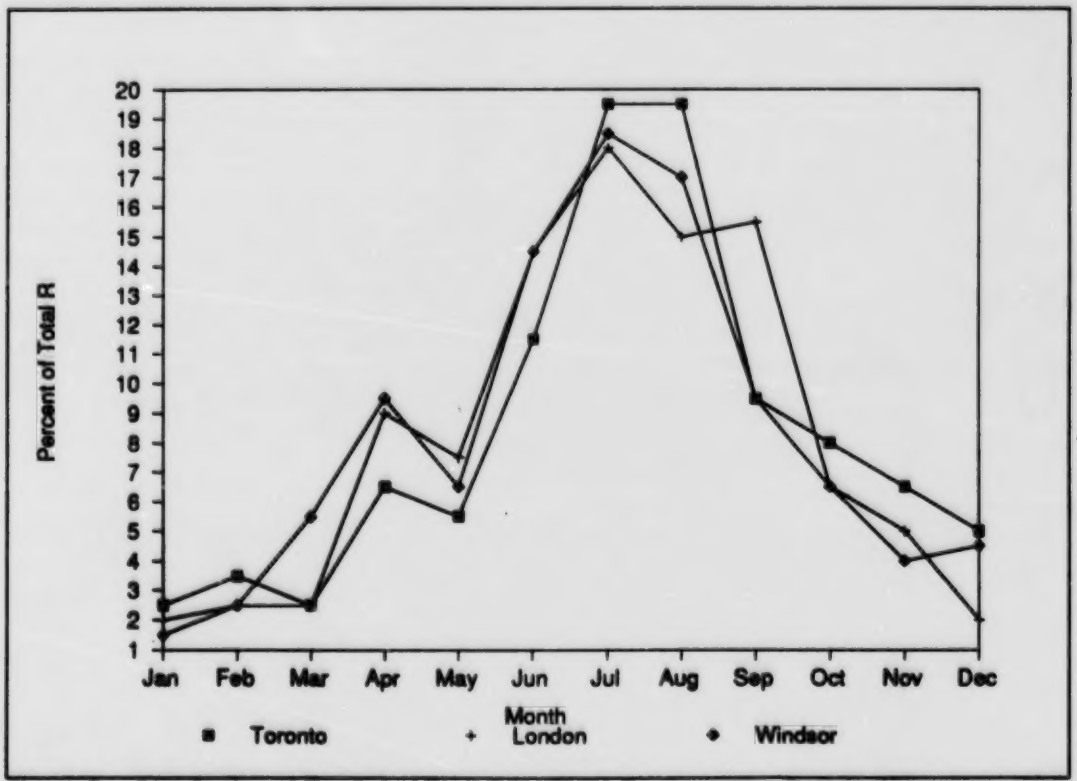


Figure 8. Distribution of Percent of Total R for Three Southwestern Ontario Cities (Source: Wall, Dickenson, and Gruesl, 1983).

6.1.2 Soil Erosion -The TED Research

The TED research evaluated the effect of tillage, cropping and water management practices in order to determine their contribution to reducing soil erosion using three main techniques:

- measurements of soil cover;
- field scale monitoring of soil and water movement; and
- estimation of soil movement through tracking ^{137}Cs levels.

The most common approach to evaluating the soil erosion control afforded by a farm practice under investigation was to assess the residue cover at one or more times throughout the season. Several of the studies measured soil loss using microplot scale rainfall simulation (Appendix E.1.5, E.2.1, E.2.2, E.2.3, E.3.8, E.4.4). Rainfall simulation provides a single time-event measurement of soil loss, and is useful in comparing management factors at the time the work is carried out. The approach of other research (Appendix E.1.2, E.3.2, E.3.8, E.6.2, E.6.3, E.6.4, E.7.1, E.7.2, E.7.4, E.7.5, E.7.6) was to document or demonstrate the impact of farm practices on soil properties, such as structural stability, infiltration, and permeability. This research addressed changes, most often over a short period of one or two years, resulting from different farming practices and attempted to link soil quality parameters to potential soil loss. Some detailed soil erosion data were collected by the University of Guelph (Appendix E.1.2, E.7.5) using ^{137}Cesium to trace the movement of soil under various tillage systems and in various landscape positions.

Farm Management Systems and Soil Erosion

One of the ultimate goals of the TED program was to develop a range of farming practices which could be combined into a system which would work for an individual farmer faced with a particular situation. It was recognized early in the planning process that if 400,000 hectares were to be brought into some form of conservation technology in a few short years that the range of options must be kept wide and allow farmers to tailor systems to their particular situation. How well a system works for a farmer will be determined by the economic returns to be realized using this system which are affected by the yield of the crop, the quality of the crop and the cost of inputs, management and capital required to grow the crop. The system will not work if it does not fit the farm management style and if it is not compatible with all relevant on-farm enterprises, including livestock. To work for soil conservation purposes, the practice must include some form of increased soil cover and should make optimal and efficient use of on farm inputs, such as crop residue and manure. Using this definition of a system that works, the TED subprogram can be conclusively judged to have studied a number of systems that work. These systems, and the mechanisms by which they are judged to reduce soil erosion are discussed below.

Soil Erosion and Soil Cover

The generally accepted hypothesis in soil conservation work is that increasing soil cover lowers the rate of erosion. A rule of thumb identified in Ontario has 30% residue cover in the spring as the minimum residue cover required to qualify a practice for soil conservation. TED research investigated a range of soil cover conditions ranging from 1% to more than 90%. The residue cover resulted from reduced tillage of crop residue, the use of cover crops, or both. Extensive rainfall simulation on fields with these practices suggest that higher residues reduce soil loss.

Regression analysis of the available rainfall simulation data relating soil loss to soil cover as the independent variable failed to provide a reliable degree of correlation (R^2=0.14). This result was not surprising due to the large number of confounding characteristics in the data set. These factors included slope, soil texture, soil infiltration characteristics, residue levels and antecedent moisture conditions.

Despite the failure of regression analysis, observations made during the TED evaluation of cropping practices suggests that residue cover is a good indicator of the degree of protection from erosion. The evidence consists of site specific observations and trends in the data which suggest that greater than 30% residue will substantially reduce the amount of soil detached from a small plot.

Data on soil cover rates and biomass levels produced from various cropping and tillage systems are presented in Table 6.1-1. These data show that a number of systems tested were successful at producing substantial increases in soil cover.

The OBATA system for crop production has the components required to address the management issues faced by many farmers. Some of the components of the system are of unproven value based on the work done in TED (e.g., the use of kelp and molasses), but other components of the system provided good soil cover, erosion control, and water quality benefits. The aeration tillage tool was shown to be effective for management and control of cover crops and as a tillage tool. Crop rotations and increased soil cover associated with the OBATA system provided significant erosion control and improved water quality when compared to conventional moldboard crop systems. This system appears to work particularly

Table 6.1-1. Residue Cover and Biomass Levels Provided by Various Tillage and Cropping Practices in TED Studies

Residue Cover %	Biomass kg/ha	Type of Residue	Time of Year	Soil Loss g/m²	Practice	Source, comments
≥85	960-3520	red clover interseeded in wheat; corn to follow	spring, prior to treatments		no fall tillage	SWEEP Report No. 36 • total 7 sites over 3 yrs. • biomass measured for only 2 sites; different sites for each time of year • rainfall- 2 different sites, 2 diff. yrs.
2-11	0-160				fall moldboard	
50-84	480-1600				fall chisel	
26-82	224-1324	red clover	after spring planting	15-17	fall chemical kill	
33-93	1275-2540			4-11	spring chemical kill	
1-13	0-407			52-190	moldboard,fall or spring	
3-57	445			108	fall chisel,with or without secondary tillage	
77-94	0	control	late fall		no-till soybeans	SWEEP Report No. 27
60-70	4-74	spring barley,spr. oats, fall rye			till and drill cereal cover crops	
87-95	6-509	spr.barley,spr.oats,fall rye			broadcast cover crops	
48-95	0-1880	all, incl. control	early spring	4-9		
25-50	0	control	after planting		notill	
16-41	0	all cereal cc.'s			till and drill	
32-81	0-1957	fall rye			broadcast	
28-49	0	spr.barley, spr.oats				
90-98		soybean - spring cereal (oats, barley)	after soybean harvest (following spring) [after plant]		broadcast at two different timings	SWEEP Report No. 52 • differences more due to site that treatments, including control • different degrees of seedbed preparation according to site.
(54-93)						
[3-67]						
88-96		control				
(56-81)						
[4-61]						
67-100		corn - spring cereal or annual ryegrass	after corn harvest (following spring) [after plant]		seeded into corn @ 12 leaf (interrow cultivation)	
(36-98)						
[7-75]						
64-96		control				
(36-93)						
[8-54]						
0-6		winter wheat residue with and without oil radish August	fall [following spring]	7	fall plow	SWEEP Report No. 58 • 2 sites each 2 years • relation to site rather than treatments of manure or tillage • rainfall at 1 site only
[0-14]				157		
18-77				62	fall chisel plow	
[11-62]				78		
57-100					spring aerway	
[19-71]				53		
37-99				2	no fall or spring tillage	
[31-88]				57		

Table 6.1-1. Residue Cover and Biomass Levels Provided by Various Tillage and Cropping Practices in TED Studies

Residue Cover %	Biomass kg/ha	Type of Residue	Time of Year	Soil Loss g/m²	Practice	Source, comments
avg. 85		winter wheat	fall [spring]		aerial seeded into soybeans	SWEEP Report No. 58 • 2 years, 1 site per year • aerial seeding at higher rate than other 2 establishment methods
[88]						
avg. 73					no-till drilling after soybeans	
[80]						
avg. 24					conventional-one cultivation after soybean harvest	
[57]						
avg. 96	69-287	ryegrass	fall		perennial and annual ryegrass varieties interseeded in corn	SWEEP Report No. 12
avg. 86	0	control-grain corn stover				
33-74		fall rye	June		disced	SWEEP Report No. 12 • 2 years, 1 site
7-90					plowed	
21					harvested & disced	
1-5					harvested & plowed	
>90					mowed	
12-45	1.93-3.78 x 10^3	rye varieties	spring		soybeans no-tilled into rye; rye mowed	SWEEP Report No. 12
88-97	523-1569	red clover frost seeded	fall		into or following winter wheat	SWEEP Report No. 12 • 3 site - years
71-100	491-3667	drilled red clover, alfalfa, crimson clover, hairy vetch				
82-97	756-3654	oilseed radish				
78-89	496-1688	buckwheat				
57-77	0	control (no cover crop)				
	1116-2619	ryegrass	November		established in or after winter wheat or barley over 3N levels applied to main crop	SWEEP Report No. 42 • 2 locations, 1 year
	2049-5231	oilseed radish				
	2262-4597	red clover				
32-91	1534-3478 (Delhi site)	rye	soybean planting		rye chemically killed, mowed and soybeans no-till planted	SWEEP Report No. 29 • rye killed either earlier or later in spring • over 2 years (1989, 90)
57-86	568-4776 (Woodstock site)					
82-84		grain corn	fall after tillage		no fall tillage	SWEEP Report No. 40 • 2 sites
53-63					offset disc	
30-56					various chisel-plow treatments	
5-11					moldboard plow	
72-82		soybeans			no fall tillage	
17-27					offset disc	
13-41					various chisel-plow treatments	
<1-9					moldboard plow	

Table 6.1-1. Residue Cover and Biomass Levels Provided by Various Tillage and Cropping Practices in TED Studies

Residue Cover %	Biomass kg/ha	Type of Residue	Time of Year	Soil Loss g/m²	Practice	Source, comments
13-34		corn	fall after tillage		full moldboard	SWEEP Report No. 31
13-34					3rd cut of the moldboard	• 4 sites, 1 year
20					Norcan minibottom	
6-20			spring		full moldboard	
15-24					3rd cut of the moldboard	
19					Norcan minibottom	
9-20			after planting		full moldboard	
8-15					3rd cut of the moldboard	
15					Norcan minibottom	

well for people who require hay and forages in their rotation and who have manure to work with in their system.

Residue cover from the use of cover crops, and even the simple inclusion of winter cereals in the crop rotation, may reduce soil and phosphorus loss under many conditions. The TED studies also indicated that legume cover crops can make a significant contribution to succeeding soybean crops. Cover crops also provide soil structure improvements as demonstrated in long-term work carried out at the University of Guelph. In particular the TED studies showed that winter wheat sown into soybeans could be very successful as a cropping strategy, both in terms of providing reasonable yields, as well as providing additional soil cover. Planting soybeans directly into a standing rye crop and later mowing the rye also proved to be an effective crop management strategy. Some producers were using the rye as a forage allowing cattle to graze prior to planting the soybeans. This is a good example of the kind of creative management of cropping systems which individual farmers developed in response to their particular needs.

As indicated in Table 6.1-1, some TED plots had residue cover in excess of 90%. This high residue cover was achieved by the use of cover crops in systems where tillage was significantly reduced. The TED evaluation suggests that the additional erosion protection due to cover crops in no-till systems, where main crop residue levels are already high, may be too small to justify the costs of cover crop management. In such systems, the use of cover crops may be justified on other grounds such as N contribution, soil improvement or on-farm use of the cover crop as forage. These potential benefits are discussed in Section 5.3.

The management of manure in an increased soil cover system was investigated in TED. Forage and cover crops were found to be beneficial in maintaining high soil residue levels which allowed for safe surface application of manure. Manure was applied in spring to rapidly growing forage crops and subjected to rainfall simulation. This study indicated that the manure application did not result in higher phosphorus loadings. However, some caution should be exercised in the interpretation because the rainfall simulation uses relatively low rainfall rates whereas a major spring event could create water quality problems even where manure is applied to a rapidly growing crop. It should also be noted that manure applied to forages or to rapidly growing cover crops cannot be incorporated in accordance with the OMAF guidelines. Work conducted under TED would indicate that it may be appropriate in future to reconsider OMAF recommendations and to allow for reasonable rates of manure application on actively growing crops. The studies did not detect environmental or agronomic difficulties with the manure rates studied.

Soil Erosion and Water Movement

A major process which impacts upon soil productivity, soil erosion and water quality is the movement of water across the soil surface, and into and through the soil profile. The relative amounts of surface and subsurface water flows, the presence or absence of direct connections to tile drains and the availability of air and water to crop roots are important in controlling soil erosion, water quality and soil productivity. For these reasons much of the TED work focused on managing the flow of water through the agricultural system.

Tests of subsoiling (Appendix E.3.2) indicated that the perception of soil compaction problems and associated reduced drainage was often greater than the reality. Subsoiling actually had the potential to decrease yields if practised as a form of interrow cultivation. The implements were not particularly efficient tillage tools. While providing a degree of soil disruption and at the same time maintaining the residue cover, the effect of soil disruption has not been found to be particularly beneficial or long lasting. Subsoiling should only be conducted when evidence is found in the soil profile of a problem which can be addressed with the tool.

Protection of good soil structure was found to be much more effective at encouraging drainage, reducing ponding and dealing with periodic drainage problems on heavy soils. These soils, containing shrinking/swelling clays, crack freely. Early in the growing season, reductions in soil moisture open up numerous cracks. The physiography of the crack network is not well known, but is believed to represent a major system of macropores which provide direct routes of water movement from the soil surface to field tile.

Associated with the shrinking of the soil is a concomitant increase in bulk density when soil peds achieve a density of up to 1.8 g cm^{-3} (Appendix E.7.4). The shrinking process, often associated with crusting of soil after periods of early season rainfall may trap germinating seeds and emerging seedlings in a compressive force substantially larger than that associated with soil compaction which may achieve bulk densities of 1.5 to 1.7 g cm^{-3}.

Several studies were conducted to determine the effect of conservation practices on the infiltration of water into the soil. Work with the Guelph Permeameter and Pressure Infiltrometer (Appendix E.6.2) as well as large scale rainfall simulation found that, in general, no-till systems resulted in significantly more runoff and less infiltration of water than conventional tillage systems. This is in direct contradiction to the findings of long-term lysimetric studies at Coshocton, Ohio. This contradiction may be partly explained by the fact that the Coshocton site is underlain by highly porous non-glaciated soil and weathered sandstone bedrock, whereas sites in southwestern Ontario are not connected to a similar conduit for water. This would suggest that the macro-pores and earthworm holes credited with reducing surface runoff in Coshocton may still be present in Ontario but not as well connected to water storage areas. The harsher winters and deeper frosts in Ontario may also disrupt the macro-pores. Despite higher amounts of runoff from no-till systems the runoff was consistently lower in sediment and phosphorus loads.

Soil and water conservation is a complex water management issue. Work in TED has supported the general understanding that if water is retained in the field and allowed to infiltrate into the soil erosion can be controlled. However, the work has also indicated that this might result in increased leaching of P into surface waters (see Section 5.2 for further discussion). The studies also suggest that increased surface protection which prevents soil detachment can have a net benefit for water quality even if the proportion of runoff is increased. Clearly continued investigation of the relationship between farm management systems, soil properties and the volumes and quality of surface and subsurface water flow is required. Continued use of rainfall simulation and The Guelph Permeameter is recommended. Field scale studies which monitor surface and subsurface flows are extremely expensive and subject to the difficulties of poor weather patterns (Appendix E.6.3, E.6.4, E.6.5). However, data from such studies are crucial to understanding the dynamic interrelationships in Ontario.

Soil Erosion and Tillage Translocation

Work conducted under the TED program has strongly supported the hypothesis that the translocation of soil due to tillage is a major factor resulting in soil erosion and soil productivity loss in areas of complex topography. It is important to note that the soil lost due to tillage translocation is not actually lost from the field but is deposited in other landscape positions. Thus this phenomenon may have a great impact on soil productivity without a corresponding impact on water quality.

The TED study indicates that sandy soils are the most fragile soil types. Soil loss in upper convex, or shoulder, slope positions in sandy soil areas has already resulted in yield losses of 30-40% of the average field yield. The productivity losses are even greater in years of climatic stress. The main mechanism of soil loss appears to be tillage translocation. Water erosion is thought to be minimal considering the high infiltration capacities of the coarse textured soils.

The consistent yield differences obtained for the benchmark sites from year to year is encouraging, and it is clear that many of the differences are related to soil loss or the effects of soil loss. This problem can be attributed almost entirely to tillage translocation. If tillage cannot be avoided, it may be possible to change the pattern of tillage. The necessity of at least alternating the direction of all tillage, including secondary tillage, cannot be overstated. The net soil losses from alternating tillage directions, while still large, were much smaller than the losses from unidirectional tillage.

Although reports of a similar study has not been found in the literature, anecdotal information available from Europe

suggests that contour plowing with a roll over plow can reduce the downslope movement of soil due to tillage. There may be other implement modifications, or modifications in the use of implements that will reduce this effect. In the TED research different impacts were noted for the same implement. The impact seems to be partly related to implement speed, tractor size, implement vibration, and operator variables. All of these factors are suspected of affecting the depth of the implement and the draft which may in turn affect the degree of translocation.

The major options to control this problem may include:

- use of no-till cropping practices
- alternating tillage directions
- using specially developed implements (eg. roll over plows) or modifying implements to allow for more effective and efficient contour plowing
- retiring land from production
- using field location technology to map field patterns of soil conditions and yield and then varying the inputs accordingly.

6.2 Phosphorus Loss

6.2.1 Phosphorus Loss - The Background

Estimation of P associated with soil loss

Consideration of P loading to Lake Erie has suffered some confusion by contractors studying under the SWEEP-TED program. The definition of estimates of total P and estimates of plant-available or soil test P have not always been made clear.

Total P is the absolute estimate of P in soil obtained by destruction of the soil fabric with harsh chemical intervention. Total P would include all fractions of P which may be identified upon separation by other techniques, including organic forms, adsorbed forms and chemical compounds in crystalline or amorphous state unique to the soil. The organic forms may be thought of as similar to the cellular contents of animal and plant cells from which they may come. Adsorbed forms include portions of P thought to be attached to surface coatings of iron or aluminium on soil particles by electrostatic or other surface phenomena. Examples of chemical compounds in soil are aluminium and ferric phosphates or calcium phosphates in crystalline or amorphous states as part of the soil fabric. Total P, because it is defined as "total" should be the same value, irrespective of the laboratory or technology used to determine it.

Extractable estimates of P are invariably designed to recover readily soluble or weakly held portions of P in the soil as estimates of plant-available, labile, or soil test P, terms used to define an empirically determined portion of soil P which can be used to judge soil fertility (an approximation of the amount of P which may be available for plant use). They are called empirical estimates because the interpretation is dependant entirely on the experience with a particular method by the community. The integrity of these tests is related to the kind and degree of dilution of the extractant, the length of time of extraction, soil particle fineness, solution temperature and degree of agitation. It might be argued that such estimates could provide good estimates of the intensity of the pollution. Because the environmental community has not developed experience with fractions of phosphorus, readers should exercise caution in making any environmental interpretations from results obtained in this manner.

Sediment and phosphorus transport by water

One of the TED objectives was to determine feasible ways to prevent sediment detachment from soil (Section 5.1). The effective use of crop residues to control sediment and P delivery is shown by a rainfall simulation study (Table 6.2-1). Red clover residues remaining on the soil surface, compared to crop incorporation by plowing, reduced runoff volume, sediment delivery and phosphorus transport by water. Inherent in this method of controlling phosphorus delivery, which is correlated with sediment delivery, is shown in Table 6.2-1. The effectiveness of red clover residues which have been left on the soil surface is indicated for the chemical kill of the crop as compared to crop incorporation by plowing. However, if nutrient stratification should cause enrichment of the surface soil, a two-fold enrichment of the sediments with P could cancel the benefit from a two-fold reduction in sediment detachment.

Table 6.2-1. Quantities of Runoff, Soil and Phosphorus Loss Following a Red Clover Cover Crop

Kill Type	Timing	Runoff Volume (L/m^2)	Soil (g/m^2)	Total Phosphorus (mg/m^2)
Chemical	Fall /88	3.9	15.3	18.7
Chemical	Spring /89	2.9	3.6	4.8
Moldboard	Fall /88	6.6	51.5	63.9
Moldboard	Spring /89	7.3	72.4	87.1

Farmers in Michigan, in collaboration with staff of the Soil Conservation Service have documented such stratification where the broadcast, surface application of phosphatic fertilizer has resulted in prominent enrichment of the surface sediments (Figure 9). Note that the phosphorus measurement was according to the Bray soil test, expressed in pounds per acre. The fact that the determination was not total P creates a problem of comparison with the information in Table 6.2-1 (Appendix E.7.9).

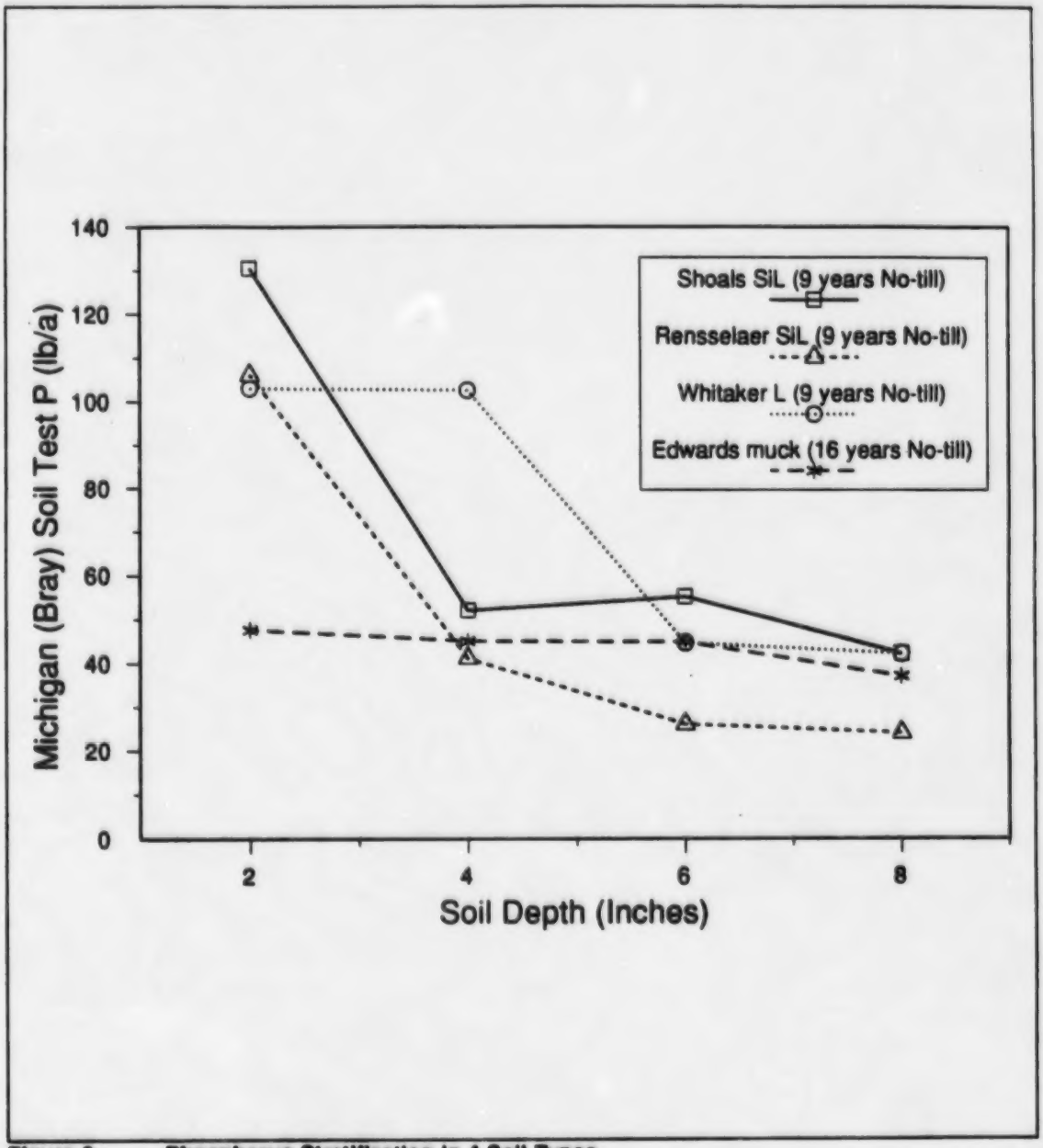


Figure 9. Phosphorus Stratification in 4 Soil Types

In a study conducted for TED, the Ontario Soil Test was used (Figure 10). Although the history of conservation tillage was much shorter in Ontario than in Michigan, the effect of management on the enrichment of surface sediments is evident. In this example the Ontario soil test, which uses a sodium bicarbonate extractant (the Olsen Method), provides another comparison which cannot be directly related to the other two examples.

In the same study, total P content of soil samples (0-15 cm) taken from 36 sites was 340 - 1200 mg total P/kg. In comparison, the soil test P of the surface soil (0-2.5 cm) was approximately 30-47 mg P/kg. While there may be a degree of proportionality between plant available P and total P in specific soil samples, there is no generally applicable relationship which can be used for extrapolation within these studies.

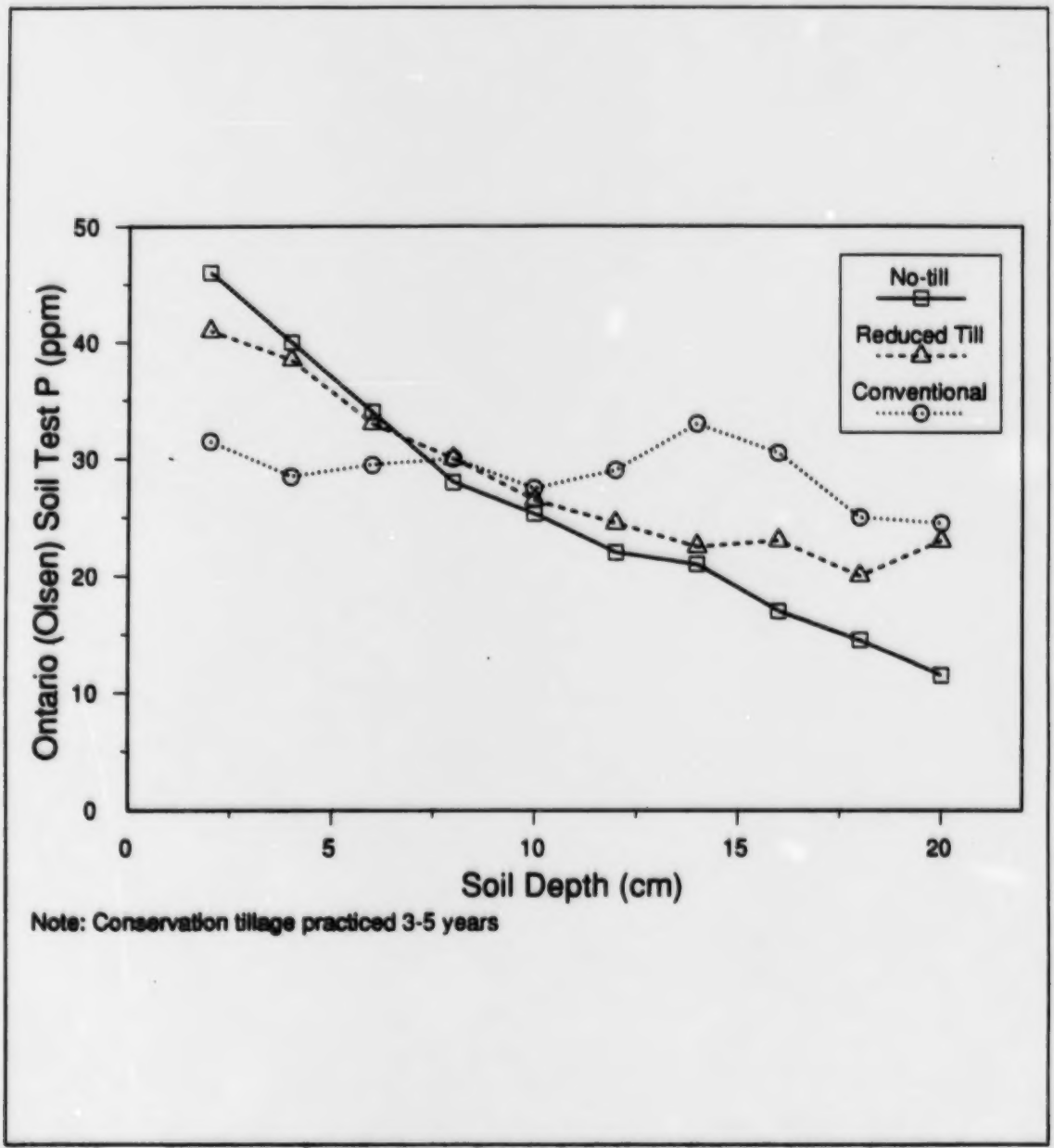


Figure 10. Phosphorus Stratification in Ontario Soils Under Different Tillage Options

6.2.2 Phosphorus Loss- The TED Research

The conventional wisdom of soil conservation research and programs to protect water quality has held that sediment loss and phosphorus inputs to receiving water courses are directly correlated. The assumption has always been that control of sediment will reduce P inputs. Significant portions of the research conducted under TED suggest that this is not necessarily so. Data on total P and sediment losses from TED research plots are presented in Table 6.2-2.

Table 6.2-2 Sediment and Phosphorus Losses from Selected SWEEP Research Projects

Project	Year or Event Date	Treatment	Sediment Loss (kg/ha)	Total P Loss (g/ha)	Soluble P Loss (g/ha)	Sediment P Loss (g/ha)	Ortho P Loss (g/ha)	Residue Cover (%)	Comments
Effects of Land Planing	1989-91 (average annual losses for the 3 year period) Note: Some extrapo-lation made	planed	86	100	40				Site 1
		unplaned	807	240	270				
		planed	129	340	190				Site 2
		unplaned	74	380	40				
		planed	302	250	110				Site 3
		unplaned	126	70	10				
Effects of Tillage on Water Quality Lowlands	1988-90 (average annual losses for the 3 year period)	ridge-till	530				965	88	
		zero-till	391				1519	95	
		conv.	897				555	< 10	
	Jan. 1 to Sept. 30, 1990	ridge-till	429	2684	2485	199	1178	89	
		zero-till	353	2391	2125	266	1701	93	
		conv.	472	1242	1046	197	587	< 10	
		sod	129	5121	4995	126	2380	100	
Effects of Tillage on Water Quality Uplands	1988-89	no-till and mb plowed	No Runoff or sediment	No P loss					
	Oct 1988	no-till	700	410					rainfall simulation at 198 mm/h intensity
		mb plow	1560	870					
	Apr 1989	no-till	900	870					
		mb plow	1980	1980					
	Jun 1989	no-till	880	3050					
		mb plow	1850	7400					
Effect of Terraces	Nov. 15/89	white beans (fall plow)	79-147	88 -163		1.9 -3.5			data from one event
PDW Essex	1989	Test	470	1280	36				
		Control	530	1220	32				
	1990	Test	1100	3670	299				
		Control	1020	3570	169				
	1991	Test	270	1060	109				
		Control	250	770	31				

Table 6.2-2 Sediment and Phosphorus Losses from Selected SWEEP Research Projects

Project	Year or Event Date	Treatment	Sediment Loss (kg/ha)	Total P Loss (g/ha)	Soluble P Loss (g/ha)	Sediment P Loss (g/ha)	Ortho P Loss (g/ha)	Residue Cover (%)	Comments
PDW Kettle Creek	1989	Test	220	590	85				
		Control	60	470	44				
	1990	Test	1870	4920	383				
		Control	510	2520	435				
	1991	Test	130	530	95				
		Control	240	870	104				
PDW Pittock	1989	Test	40	460	127				
		Control	60	480	104				
	1990	Test	120	900	538				
		Control	90	1040	217				
	1991	Test	130	710	129				
		Control	260	930	90				

Long term monitoring of controlled drainage plots at the Woodslee research station has detected extremely high P inputs to surface and tile drainage waters from plots of permanent bluegrass sod with very little sediment loss (Appendix E.6.4 and Table 6.2-2). These observations run contrary to the expected result. Based on current understanding of phosphorus and soil chemistry the P should react with soil particles and should not reach the tile drainage system.

An attempt was made in some of the TED research to understand the role of crop residues in contributing to soluble nutrients in the soil and surface runoff.

Miller *et al.* (Appendix E.4.2) leached residues of ryegrass, oilseed radish, and red clover under laboratory rainfall simulation conditions. The concentration of soluble P in leachate was greatest for oilseed radish where soluble P was as much as 14 ppm P. Red clover produced relatively low P concentrations in leachate of up to 5 ppm P.

These amounts are considerably greater than those found by Evans (Appendix E.7.3) on incubating residues in soil and leaching the soil. This method produced 1.2 ppm of total soluble P from alfalfa residues and 0.55 ppm P from corn residues. Orthophosphate-P concentrations were lower than those of total soluble P.

The studies could not clearly determine whether the increase in soluble P levels in soil in association with crop residues was due to release of mineral bound P or an increase in residue derived organic P. Under contract by TED, Evans developed a method of determining dissolved organic P in soil solutions and this method should be useful in understanding the role of organic residues on P solubility in the future.

The patterns of release of soluble P were similar to those of soluble organic carbon (Appendix E.7.3). Unlike soluble P, soluble organic C release from residues was similar for both alfalfa and corn. Soluble organic carbon reached a maximum of 2800 and 3000 $\mu g\ ml^{-1}$, or approximately 950 $\mu g\ C\ g^{-1}$ OD soil. These values are higher than those reported by Miller *et al.* (Appendix E.4.2) as leached from the residues. Miller obtained values of 33, 72, and 18 kg dissolved organic C ha^{-1} for ryegrass, oilseed radish, and red clover, respectively, or an estimated equivalent of 17, 36, and 9 $\mu g\ g^{-1}$ OD soil.

However, values obtained by Evans were similar to those obtained by Voroney *et al.* (Appendix E.7.8) who was studying organic acids as phytotoxins. In both incubation studies, quantities of release of carbon peaked at around 14 to 16 days (at 25C).

In Voroney *et al.*'s study, rye residues produced a maximum 750 μg total VFA-C g^{-1} OD soil and a maximum of 115 μg total phenolic-C g^{-1} OD soil (@ 25C). Phenolic compounds are initially leached from residues while VFA's are by products of fermenters.

Carbon is important as an energy source for microorganisms. McKenney and Drury (Appendix E.4.3)

studied the effects of farm management on denitrification. Background denitrification levels in Brookston clay soils were not correlated with tillage systems in a corn system. Potential denitrification, measured by adding nitrate so that the system is not limited by N nutrition, was shown to be greatest for a Kentucky bluegrass system and lowest for conventionally tilled corn. Generally the levels were low, particularly below the uppermost soil layers, consequently denitrification was not considered to be effective at reducing nitrate loss by leaching. Potential denitrification, in the presence of added nitrate in this study was considered to be an index of available carbon.

Recent research by McKenney (McKenney, personal communication) suggests that different residues release different types of compounds on their decomposition. Further, the extent of denitrification depends on the specific type of C-compounds produced.

Hence, quantities of dissolved organic C appear to be largely a result of decomposition of residues rather than simply leached from residues. Management of residues through incorporation or leaving residues on the soil surface does not appear to affect the production of soluble organic C. The release of soluble P generally corresponds with the release of soluble organic C and does not appear to differ according to the type of tillage. Greener residues, such as those of alfalfa, produced higher levels of soluble P but not soluble organic C according to Evans' study, while Voroney *et al.* found that greener, fresher, residues produced more organic acid-C believed to be phytotoxic, than weathered or more mature residues. The amount of soluble P and soluble C leached under simulated rainfall varied considerably among residue types.

The implication of significant P loadings to streams without significant sediment loss is that control measures aimed at reducing the amount of P delivered to Lake Erie may be less effective than initially predicted. This possibility strikes at the root of one of the main objectives of TED and requires further study to ensure that recommended conservation farming measures address both soil productivity and water quality issues.

Several times during the TED study, the question of the relative impacts of various forms of P on Lake Erie was raised. One response has been that the form of P is irrelevant since it is all potentially available to promote plant growth once it reaches Lake Erie. This may be true in the long term, but research has raised the possibility that conservation farming practices may alter the short term dynamics of the P cycle both on the cropland and in the water. The impact of this possibility on the goal of improved water quality in Lake Erie should be investigated.

6.3 Soil Quality and Long Term Productivity

6.3.1 The Background

The improvement of soil quality parameters which reduce soil erosion and improve or maintain soil productivity was an objective to be achieved with conservation farming technologies. Primary causes of erosion-induced productivity losses were considered to be nutrient deficiency, structural degradation, and loss of available water holding capacity (Langdale and Shrader, 1982 and Battiston et al, 1987, in lit review).

Existing eroded areas were recorded to possess lower fertility and lower available water holding capacity than non-eroded soils, in addition to having lower organic matter and less desirable soil structure (Battiston and Miller, 1984 in lit rev.). It has also been recognized that where erosion significantly reduces the extent of the root zone and the associated available water holding capacity, technology will not be able to compensate yield reductions (Young, 1980 in lit rev).

The background paper identified soils with structural degradation causing yield loss as characterized by poor drainage, ponding and poor seedling emergence. Soil management practices that improved infiltration, drainage and soil structural stability were linked with objectives of reducing soil erosion and increasing or maintaining soil productivity.

Cropping and tillage practices, in addition to soil amendments such as manure, were expected to affect soil properties but there is little indication of the extent and the length of time that the improvement may be effective. In addition, the extent to which practices can be effective as corrective measures to improve soils with extensive degradation is questioned.

Compensating for lost soil fertility has been considered effective with the addition of fertilizers to improve crop yields (Langdale and Shrader, 1982 in lit rev.) although it is considered more difficult to correct nutrient deficiencies when they are accompanied by unfavourable sub soil conditions (Crosson and Stout, 1983 in lit rev). For example, applied nitrogen was rapidly leached from eroded sites having coarse subsoils and low water retention (Battiston and Miller, 1983 in lit rev.).

Soil structure is considered to control the ability for water to infiltrate soil and for soil aeration (Crosson and Stout, 1983 in lit rev). The loss of soil structure occurs due to compaction and loss of organic matter. Several studies

cited in the literature review (Ketcheson, 1980, Vyn and Daynard, 1984, and Angers et al, 1987) showed improved aggregate stability and aggregate strength in forage based systems versus soybean and corn systems. Changes in these soil properties appeared to develop quickly under a forage regime and decrease rapidly following the introduction of corn. Sometimes the rate of loss of structural stability induced by grain corn production was faster than the rate of gain induced by bromegrass production (Baldock and Kay, 1987 in lit review).

6.3.2 THE TED RESEARCH

The impact of conservation farming practices on a range of soil conditions, which together could generally be termed soil quality, was recognized early in the planning process of the TED research. However, the general consensus was that many of the parameters which would be part of the measure of soil quality, such as organic matter content, would change too slowly to be measured empirically over the life of the study. There was also no clear agreement as to what soil characteristics constituted soil quality and how to recognize beneficial or detrimental changes in soil quality. Despite these limitations, some attempts were made in TED to contribute to the understanding of the impact of soil conservation techniques on soil quality.

One measure of soil quality which was investigated in TED was the ecology of the soil flora and fauna. Small-scale studies (Appendix E.7.6 and E.7.7) provided details on the soil flora and fauna population under various agricultural systems and the response of soil flora and fauna to disturbance. Using measures such as the biomass of soil organisms, decomposition rates of residues, the stability of soil flora and fauna populations and the diversity of these populations it was concluded that agricultural fields under low tillage systems have similar qualities as pasture fields. In addition there was evidence that some of these measures of soil quality recover quickly after plowing. This study also measured physical indicators of soil quality, including saturated hydraulic conductivity and dry soil bulk density. These investigations generally supported the theoretical relationship that increased soil biomass and biopores would result in better water infiltration characteristics. The second of these studies looked at the distribution of invertebrates in agri-ecosystems. Invertebrate abundance and diversity was assumed to be an indicator of soil quality, in so far as the increased populations and species diversity would be advantageous for natural predator control of pests, decomposition and nutrient cycling. This study concluded that the field size and distance from woodlots and fencerows is a more important determinator of soil invertebrate populations than is the type of tillage or crop. This conclusion suggests to TED that the distribution of invertebrates as a measure of soil quality, field size and the presence of adjacent woodlots and windbreaks may be at least as important as the infield farming practices.

Many of the studies conducted under TED attempted to examine physical indicators of soil quality. Generally accepted physical indicators of high soil quality include a stable, well defined soil structure; stable soil aggregates; the absence of impermeable or compacted soil layers, etc. These physical characteristics affect the ability of the soil to transport and hold water, the ability of crop roots to penetrate the soil to find nutrients, and moisture; and interact with the biological and chemical properties of the soil to provide a good healthy growing medium. Detailed investigation of these physical characteristics of soil is very difficult and expensive. In addition, changes can occur over long periods of time. For this reason, the TED observations on soil physical qualities were generally obtained through the measurement of properties which are related to physical structure such as infiltration rates and bulk density. This study yielded some interesting results, such as the lower than expected infiltration rates on some no-till soils and evidence that plowing increases the hydraulic conductivity of pasture soils, while it decreases the hydraulic conductivity of no-till soils.

In the TED planning process, a number of individuals expressed concern about the use of anhydrous ammonia and its impact on soil quality. A TED study was conducted to investigate the nature, magnitude and duration of soil quality effects of anhydrous ammonia. This laboratory study investigated only the physical responses of soil to anhydrous ammonia and had to make inferences about the biological implications of these physical responses. However, the study found that there was a relatively small zone of damage associated with the anhydrous ammonia and that there was very quick recovery of aggregate stability and soil pH within the zones of influence. The inferences are that proper use of anhydrous ammonia may not have large and lasting impacts on soil quality.

Some work was done in TED to investigate the role of cover crops in the nutrient balance of a field. Imbalances of nutrients, nutrient leaching and loss of nutrients to volatilization are considered to be issues of soil quality and long term productivity. The TED research used two basic approaches to investigate this question:

1. applying excess nitrogen to the system in order to allow it to be scavenged by cover crops (Appendix E.4.2); and
2. planting into soil where nitrogen could be expected to be a limiting nutrient in order to

detect any crop response to N contributed or scavenged by the cover crop under study (Appendix E.2.3).

Miller *et al.* (Appendix E.4.2) found that rye grass was effective at immobilizing nitrogen. Different TED studies formed different conclusions on the value of oilseed radish as a scavenger of nitrogen. Work by Miller indicated that the oilseed radish was effective in tying up nitrogen, however the nitrogen was released from the oilseed radish residue too early the following year to be protected from leaching although the biomass of unfertilized corn tended to be higher after oilseed radish relative to the check. Samson *et al.* (Appendix E.2.3), using a different methodology, came to the conclusion that oilseed radish played a role in maintaining water quality by picking up excess nitrogen in the fall and also contributed to crop yield by releasing this nitrogen in the spring. The latter conclusion was supported by no response in corn to N fertilization following oilseed radish but a response to N in the absence of a cover crop. Clearly, further study using a combination of the two approaches will be required to resolve some of the confusion over the timing of the nitrogen uptake and release, and the agronomic and environmental benefits of cover crops as nutrient scavengers.

The small amount of soil quality work done in TED simply reinforced what was already known. Soil quality is difficult to define and to study. It requires long-term permanent observation plots where integrated methods for observing changes in the physical, chemical and biological properties of soils can be developed and tested. Several hypotheses relating to conservation farming practices and long term soil productivity were listed in the Background paper. Conservation practices involving reduced tillage, crop rotations and increased crop residue were hypothesised to have the following effects:

- improve soil structure and water holding capacity;
- increase the diversity and health of soil flora and fauna;
- result in more stable nutrient dynamics;
- stabilize and gradually increase organic content; and
- improve the long-term productivity of the soil.

There was an implicit assumption that if these practices could be implemented at a reasonable cost with no significant short term yield penalties that their adoption would also result in improved economic sustainability for the farmer. The work done in TED was too short term and not designed to test these hypotheses. However, nothing in the extensive observations and comprehensive yield measures from TED suggest that these hypotheses, and the corresponding assumption regarding the economics of conservation farming should be revised.

6.4 SUMMARY

Consideration of the results of the TED research and reference to other ongoing studies results in the following conclusions. In some areas the conclusions are fairly self-evident and serve only to support or confirm understanding that was available before the beginning of the TED subprogram. In other areas the TED research has provided significant new information which has led to understanding which was not available before the program began. For example, the conclusion that soil cover reduces erosion is not new, however, the conclusion that tillage translocation results in a significant amount of soil erosion and phosphorus movement which does not necessarily correspond to water quality problems is a significant new finding from the TED research.

6.4.1 SOIL EROSION

The main conclusions to be drawn from TED work on soil erosion are as follows:

- increased soil cover leads to reduced soil erosion;
- tillage translocation is a significant component of soil erosion on lands with complex topography;
- soil erosion can be linked to intrinsic soil properties which affect crop productivity and yield, such as water holding capacity;
- the use of percent soil cover as an indicator of protection from erosion is a useful indicator by which to rank conservation practices. All else being equal, the more crop residue which a practice leaves, the greater the erosion protection afforded. Unfortunately, this relationship is confounded by other variables within the agricultural system, such as the slope, soil texture, soil structure, seasonal timing of the residue cover, and physical characteristics of the residue which relate to soil holding capabilities;
- the relationship between infiltration rates and soil erosion is not clear. Conservation practices evaluated under TED which resulted in reduced water infiltration rates and increased surface runoff were at the same time able to substantially decrease the amount of sediment carried in that runoff. Therefore,

in some cases, reduced infiltration may be correlated with reduced erosion, despite increased runoff.

6.4.2 WATER QUALITY

The major conclusions to be drawn regarding water quality impacts of conservation practices evaluated under TED are as follows:

- the estimation of the total amount of phosphorus which leaves crop land and enters adjacent water courses is extremely difficult or impossible to make under plot-sized conditions. The portion of the phosphorus load associated with sediment varies in response to the ability of the drainage patterns to transport that sediment directly into water courses. The portion of the phosphorus load associated with dissolved substances is dependant upon a complex chemical and biological system which is not well understood. For these reasons, there are no absolute numbers for the phosphorus load reduction due to any particular conservation practice. It is possible to rank conservation practices in a general way based on their ability to reduce phosphorus loading, but even this process is difficult and not yet well developed;
- techniques for measuring the total amount of phosphorus lost on an annual basis from field research plots are not well developed. None of the TED projects were sufficiently instrumented to enable absolute measurement of the total amount of phosphorus lost from the plot on an annual basis. A process of extrapolating from an event based monitoring system to annual P loads is also inadequately developed and risky. However, the partial data set gathered here indicates that the range of annual phosphorus loss is in the area of 0.5 kg/ha to 2 kg/ha per year. Assuming that these figures are relatively accurate, implementation of conservation technologies will need to be very efficient at eliminating the phosphorus loss if they are to result in an average of 0.5 kg/ha/yr reduction in P loading;
- preliminary TED work on the nitrogen cycling under conservation tillage indicates that conservation practices can probably be implemented without running the risk of increasing nitrogen contamination of ground waters;
- increased soil cover which is beneficial from an erosion control standpoint, may actually increase phosphorus loss to watercourses;
- the wide-spread adoption of conservation tillage, if done properly and in accordance with good agronomic management practices, will not require increases in the amount of farm chemicals applied. Extensive monitoring work conducted under TED indicates that there is no great danger of increased pesticide contamination of ground or surface waters under conservation tillage.

6.4.3 SOIL PRODUCTIVITY, FARM MANAGEMENT AND OTHER CONSIDERATIONS

The following general conclusions regarding soil productivity and farm management are drawn from the TED research:

- the adoption of the conservation farming practices studied under TED would appear to be, at least, revenue neutral. The practices tested did not result in any significant yield reductions when compared to conventional practices. The conservation practices also did not result in any significant increase in capital or input costs when compared to conventional farm practices. In fact, the experience of many farmers indicates that the adoption of conservation farming practices can actually reduce input costs, while maintaining yields, thereby improving the net return to the farmer;
- the above observation is based on the adoption of such practices by knowledgeable and experienced farm operators. During the transition, or learning period, there is admittedly some risk of management mistakes leading to reduced yields or increased input costs. Therefore, improved support mechanisms to assist farmers during this transition phase would be useful in encouraging the wider adoption of conservation farming practices.
- cover crops may be a helpful conservation practice for farmers who don't wish to, or cannot, move to a no-till system as soil cover can be maintained at significant levels, especially over winter.
- cover crops are difficult to manage under a no-till system and may not be justified by the increase in soil cover, compared to main crop residues. However, properly managed cover

crops offer a number of benefits other than increased soil cover which may make them attractive to farmers in a no-till system.

- cover crops may be particularly valuable to those adopting conservation farming practices in a livestock operation.
- farmer involvement in research planning design and interpretation is crucial to ensure that the results are relevant.
- In order to maximize benefits from farmer involvement in developmental research, teams must include technically competent people to monitor and measure parameters which will add to the data required to support and improve our understanding of the complex interactions involved in sustainable agriculture. It must be relevant to the farmer; but it must be accurate and reproducible in sufficient detail to be useful to science.

7. CONCLUSIONS AND RECOMMENDATIONS

In many respects the TED program can be viewed as an experiment in developing a different approach to research planning, research administration and technology transfer. The partnership between a government scientific authority and a private sector management contractor is unique in the history of agricultural research in Ontario. The various groups of people involved required the development of partnerships involving farmers, government researchers and administrators, and research contractors in the private sector. Thus, the process of designing and delivering the TED project had three experimental components: government-private sector partnership in management; farmer-scientist-private contractor partnership in experimental design and conduct; and use of a broad systems approach to control the design and management of the project.

At the same time as the TED program can be viewed as an experiment into a new process for research management, it was also required to deliver some tangible products. These products included:

- data which could be used to evaluate the impact of various conservation farming technologies on: soil erosion; phosphorus delivery to Lake Erie; long-term soil productivity and quality; and farm economics;
- conservation farming tools which should include revised cropping, pest management, tillage and water management practices as well as prototypes of equipment to implement these new practices;
- improved understanding and hypotheses relating to the natural processes controlling agricultural productivity, soil erosion and phosphorus delivery to the Great Lakes;
- improved research methods to evaluate the impact of conservation technologies; and
- increase in the expertise among researchers, extension personnel and farmers relating to the use of conservation farming practices.

Presented in the following sections of the report are the conclusions and recommendations derived from a consideration of the TED program based on the requirements noted above. The first group of questions relate to the success of the program as an experimental process for planning and delivering a research program. The second set of questions focus on the products that this experimental process delivered and on the ways in which these products can be further developed and enhanced.

7.1 THE TED PROCESS

Conclusion

The partnership between a private sector management contractor and the scientific authority provided an effective and efficient method of planning and delivering a comprehensive, well controlled, research program. The scientific authority was able to concentrate on strategic program directions while the management contractor focused on the day-to-day management of budgets and schedules. The resources and experience of the private sector management contractor were used to plan, organize and deliver extensive planning and review workshops, while the scientific authority was free to ensure that the most appropriate groups and individuals were involved in the process.

Recommendation

Future large-scale multi-disciplinary research programs funded by the federal government continue to build on the success of this collaborative approach to program management.

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Conclusion

The SWEEP program was a successful partnership between the federal and provincial governments with an appropriate level of involvement on the part of farmers and private research contractors. There was a large degree of cooperation and mutual support evident among all components of the SWEEP program. Unfortunately, due to different administrative and decision-making realities, the provincial government and federal governments did not initiate and end their programs at the same time. This created difficulties and reduced the effectiveness of the cooperation throughout the program. For example, Tillage 2000 was begun in 1985 and completed in 1990. The TED subprogram of SWEEP did not begin work until 1987 and completed its studies in the year 1992. Tillage 2000 was an extremely important resource for the TED program, and losing access to Tillage 2000 field sites and expertise part way through the TED project was a serious impediment.

Recommendation

Future federal/provincial cooperative research programs should be encouraged. Any necessary administrative changes which would allow these programs to begin and end at the same time should be negotiated between the two governments.

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Conclusion

Considerably more time, effort and money, involving a wide group of expertise, was allocated to the planning and review of the TED subprogram than is normally anticipated for a federal research program. This planning paid dividends by ensuring that the research conducted was relevant to the problem at hand. Each of the groups involved in the planning added their own particular expertise and perspective to ensure that the decisions were based on a comprehensive understanding of research needs and priorities throughout the agricultural community. The private sector involvement brought strengths in strategic planning and communication. The involvement of academic and government scientists ensured that the scientific background was as complete and accurate as possible. The involvement of farmers ensured that the research decisions were made with complete understanding of the real economic and farm management problems to be solved. Of special note is the fact that farmers involved in the early planning of TED recognized that they did not represent a cross-section of the entire farming community and recommended to the program administrators that additional farmers with differing perspectives be included in the process.

Recommendation

The breadth and depth of the planning exercise conducted for TED should be considered as a starting point for the planning of future research endeavours. It is particularly important to have all parties responsible for the delivery of the research program involved in the planning at the earliest possible opportunity. This would involve those with administrative, scientific, extension and implementation responsibilities. The people who will be expected to use the end results of the program should be allowed to have a major say in the shape and content of the program.

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Conclusion

The basic strategy in dealing with the research contractors under the TED subprogram was one of consultation and joint problem solving. The specification of contract requirements and the evaluation of the quality and suitability of products delivered was done with the able assistance of Supply and Services Canada. When the inevitable research problems related to weather and equipment failure cropped up, the response was characterized by joint problem solving sessions and attempts to make the best use of the available data. This approach resulted in excellent performance in the delivery of projects on time, on budget and with high quality results. Only in two or three of the 53 research projects was there any indication that contractors had failed to respond to this conciliatory approach. In these cases, strong corrective measures were required to achieve a satisfactory conclusion. These situations only serve to accentuate the excellent cooperation and effort generally afforded by the research contractors.

Recommendation

Management of future agricultural research projects should continue to recognize the vagaries of weather and equipment performance and implement a joint problem solving approach between program administrators and program researchers to solve the resultant problems and make the best use of whatever limited data are available.

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Conclusion

The consistent use of a systems approach to the TED subprogram and the emphasis at every meeting on attempting to consider all technology from a broad systems perspective was a sometimes difficult, but always necessary exercise. A systems approach forced improved communication and discussion at two levels. First, scientists were required to think in a truly interdisciplinary manner. Soil physicists were required to cooperate and discuss their work with soil microbiologists and crop scientists. Agricultural scientists were required to discuss their approach and findings with social and economic experts. On the second level, the systems approach encouraged a useful dialogue to develop between farmers and research scientists. The scientist was forced to consider the ways in which results of their research might be applied at the farm level, while farmers were forced to consider whether certain perceptions which they held regarding the efficacy of agricultural practices were scientifically valid.

Recommendation

Future agricultural research programs should accept the challenge and tremendous opportunity inherent in a true systems approach. The temptation to reduce agricultural problems into separate components and then conduct isolated research on these components should be resisted. This is not to say that well conceived and designed, rigidly controlled, scientific experiments into components of the problem are not required. In fact, such studies were an important part of the TED program. However, these studies must be based on mutual agreement of all people involved in the program that they are important and enhance the system understanding.

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7.2 The TED Products

This section of the report presents conclusions and recommendations relating to the products delivered by the TED program. These products are divided into three general categories: data, tools and expertise.

7.2.1 DATA

PHOSPHORUS LOADING

Conclusion

The TED subprogram demonstrated the possible existence of two important phenomena. First, extremely high erosion rates can be sustained in areas of complex topography without correspondingly high phosphorus delivery to surface water courses. Second, low erosion rates may result in high phosphorus delivery to surface waters in the lowland clay areas. Thus, a focus solely on controlling erosion will not adequately address the issue of phosphorus inputs to Lake Erie. However, this conclusion is based on small-scale research and should be tested against the conclusions of the watershed level studies conducted under SWEEP. It should also be noted that this is only a relative relationship. Erosion occurring in complex topography is still contributing to the phosphorus load of Lake Erie and should be addressed.

Recommendation

Future strategic planning and incentives aimed at phosphorus reduction should bear in mind the relative degree of the problem under different cropping systems and landscape types. This consideration will be greatly abetted through interpretation of data from all components of the SWEEP program. Incentives can then be targeted for maximum effect.

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Conclusion

Annual phosphorus delivery from some areas may be less than one kilogram per hectare. This calls into question the achievability of the 200 tonne reduction through the conversion of 400,000 hectares into conservation tillage. For some crop lands the maximum potential reduction in phosphorus loading possible under any tillage system may be significantly less than 0.5 kg/ha/yr.

Recommendation

The results of the SWEEP study should be used to refine the 400,000 ha target. In some areas, it may be possible to reduce annual phosphorus loading by more than 0.5 kg/ha, in other areas it may not be possible to reach this target.

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EROSION

Conclusion

When all else is equal, increased soil residue cover will decrease soil detachment and soil erosion. However, some conditions arising from the effect of management on the water infiltration and water holding capabilities of the soil may have more impact on erosion than the resultant residue cover.

Recommendation

Soil residue cover should be used as a main criterion for determining the erosion protection afforded by farming practices. However, additional studies and work should be conducted in order to find additional field measures which estimate the erosion protection benefits relating to soil structure and infiltration characteristics.

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Conclusion

A great majority of the soil erosion from shoulder slope positions in fields with complex topography is caused by tillage translocation. In some fields, these areas can be quite small and randomly located throughout the field. This raises an extremely difficult question regarding methods for protecting such spots from loss of productivity due to excessive soil erosion. One of the most effective options is to significantly reduce or eliminate tillage in those fields. This will not be a viable option for all farm managers. Other options include taking the areas out of crop production or changing tillage directions and practises. There will be difficult decisions facing each individual farmer faced with such a situation.

Recommendation

Future government programs designed to identify and protect fragile lands should attempt to address the complexity of the issue and recognize the variety of options available to deal with the problem. Subsidies and incentives should be flexible enough to allow the farm manager to make the decision which is most appropriate to the particular circumstances.

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ECONOMICS

Conclusion

TED research was conducted on relatively small field plots or under the best circumstances, at the level of a single field. Great efforts were made to collect data which would be useful in a farm level economic analysis. However, it is extremely difficult to take the types of economic data collected under TED and extrapolate to the farm enterprise level. At a very simple level of economic analysis, it was concluded that the great majority of conservation techniques tested within TED were at least neutral in their impact on net farm revenue, and several showed great promise to increase net revenue at the field level.

Recommendation

Data on conservation farming practices obtained at the field scale should be used primarily for simplified net economic return analysis. Even relatively crude estimates of the yield and cost of inputs at the field level can be used to determine net return for conventional practices versus conservation practices. Practices which are clearly uneconomical at this level of investigation can be discarded for future consideration while practices which show some promise of being comparable can be investigated in more detail.

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Conclusion

There is an extremely wide range of approaches to implementing conservation farming technologies. These approaches range from huge capital investments and major shifts in equipment and farm management practices to relatively inexpensive equipment modifications conducted in the farm shop. Individual farmers tend to take an approach between these two extremes which is comfortable to them in terms of their experience and risk threshold.

Recommendation

All economic analysis of conservation technologies should recognize the extremely wide range of risk aversion in farmers and attempt to communicate in a meaningful way elements of risk associated with projected economic performance.

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Productivity and Soil Quality

Conclusion

Soil quality may degrade quickly in response to farm management practices as was demonstrated in the tillage translocation work. There were no correspondingly rapid increases in soil quality in response to farm management discovered through TED. Therefore, soil productivity improvements due to conservation tillage practices are long-term phenomena and must be studied through long-term projects.

Recommendation

A network of long-term permanent benchmark sites, such as were established during the Tillage 2000 studies, should be established throughout the province. Long-term sites should be in place for ten years or more and should be linked to laboratory studies and modelling exercises.

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Conclusion

There is still no adequate, agreed upon, definition of what constitutes soil quality and how soil quality is linked to long-term soil productivity. Some good work was conducted under TED looking at isolated components and attributes of the soil, such as the carbon cycle, phosphorus solubility, dynamics, rhizosphere effects and the production and elimination of allelopathic compounds. In addition, the physical attributes affecting infiltration and water movement were examined. Some preliminary work was done on the soil organisms and their response to our management practices. However, it was outside of the time and budget resources of the TED program to look at integrating these various studies into an acceptable workable definition of soil quality and the effects of soil quality on long-term productivity.

Recommendation

Future research should focus on integrating the various physical, biological and chemical properties of soil into a working model of soil quality and soil productivity. This work will require the long-term soil plots referred to above which should be instrumented with the best available technology, such as rhyzotrons, soil gas monitoring devices, lysimeters and new data collection techniques as they become available.

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Conclusion

The use of single focus solutions (e.g., subsoiling for compaction) appear to be of limited value in addressing soil degradation problems. Changing farm management practices to prevent the soil degradation is much preferable to attempting to find simple technological solutions which may have a temporary effect on the problem, but which allow the problem to reoccur as soon as the old farm management practices are reinstated.

Recommendation

Future work should emphasize preventative measures rather than cures for soil quality degradation.

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Conclusion

Many of the soil conservation practices investigated in TED appear to be capable of sustaining the productivity of the soil over the long term. However, there are a great many severely degraded sites throughout the province which will require some active rehabilitation and remediation to restore them to productivity.

Recommendation

In addition to focusing on farm management changes which will prevent soil degradation, work needs to be conducted into rehabilitating the severely degraded areas which currently exist. Prime candidates for such rehabilitation development would be the severely eroded shoulder slope positions in complex topography fields.

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7.2.2 TOOLS

Conclusion

The work conducted in TED resulted in the availability of improved and new tools for use in conservation farming. Advances were made in the areas of seed and fertilizer placement, tillage options, weed control and herbicide use, and manure management practices. These advances need to be widely promoted and tested throughout the SWEEP study area and the tools should be made available to farmers on a trial basis. Two components of the SWEEP program which appeared to serve these ends extremely well were the soil conservation advisors and the availability of conservation equipment on a loan basis.

Recommendation

Soil conservation extension staff need to be distributed throughout the SWEEP area in sufficient numbers to enable them to develop and maintain an understanding of the specific soil and crop conditions and farm management systems in their areas of responsibility. So far as it is possible, there should be continuity in these positions so that farmers and extension staff are able to develop a good working relationship. In addition, these extension staff should be given the means to acquire, transport, demonstrate and lend various pieces of conservation farming equipment.

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Conclusion

Very few farmers want or need rigidly prescribed conservation farming systems. Rather, farmers need access to a range of tools and the information to allow them to make intelligent choices which relate to their specific situations. However, it will be difficult, if not impossible to reach 8,000 farmers with this type of site specific information by relying on one-on-one contact through field extension staff.

Recommendation

Put as many qualified, dedicated individuals into the field to work with farmers as budgets and administrative constraints will allow, but give these staff the most advanced farm management decision support tools available so that they can assist, on a meaningful level, the widest range of farmers.

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Conclusion

The first phase of the farm management decision support framework developed under TED was well received by farmers and researchers. It showed promise of being able to assist farmers in understanding the risks associated with different farm management choices, and has the potential to be an excellent extension tool.

Recommendation

Continue development of the farm decision support framework through Phases 2 and 3.

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Conclusion

A number of useful research methods and tools were developed during the course of TED: egs. the Guelph Pressure Infiltrometer, the ^{137}Cesium soil movement tracking, a method for monitoring the impact of water management structures and others.

Recommendation

The continued development and use of these tools and methods should be supported and encouraged in future research efforts.

*****

Conclusion

There is a need for a permanent, impartial body which can collect, organize and make available information on conservation farming practices.

Recommendation

The role of the Soil and Water Conservation Information Bureau and the Ontario Soil and Crop Improvement Association as independent support mechanisms and communication channels should be enhanced and supported.

*****

7.2.3 GENERAL

Conclusion

The data collected under TED exhibited extremely high levels of variability as would be expected in the evaluation of a natural system which is subject to climatic, biological and chemical variability. This level of variability in the data is one of the greatest areas of miscommunication between farmers and scientists. Farmers, with their practical focus like to use combine strips as a measure of yield, while many of the researchers with a scientific focus prefer to select small plot areas for yield. Neither of these two approaches is better than the other, they both involve compromises. The field-scale yields are most meaningful to a farmer, however they represent an average of a highly variable, across the field, yield pattern. The small plot yields allow the researchers to focus on more site specific conditions and attempt to explain some of the variability in the yield across the field. However these yields are often meaningless to a farmer attempting to decide whether a certain production system makes economic sense.

Recommendation

Encourage farmers and researchers to understand the other's need for data collection at a scale which is appropriate to their decision making. Future technological advances, such as combines capable of making detailed field yield maps may be capable of providing both researchers and farmers the scale of data collection which they require.

*****

Conclusion

Some researchers still confuse the goals of applied or developmental research with those of pure or basic research. It is sometimes necessary to compromise experimental design and statistical rigour for the sake of involving the end users of a technology in the development of that technology. In this type of work the primary question is not how it works, but how it can be made to work most reliably and in a cost-efficient manner. This type of developmental research is best conducted where the basic processes are well understood and the theory is strong.

Recommendation

Future agricultural research programs should contain a strong emphasis on applied research in the farmer's field. This emphasis should only be placed where basic research has given us an adequate understanding of the basic processes.

*****

Conclusion

While many farmers are keenly interested in the design and findings of research projects, very few commercial farmers have the time required to manage such a project. Typically the busiest times for data collection are also the busiest times in the business of farming. Therefore, farmers have an important role to play in advising on the design and interpretation of experimental results but should not be expected to manage the actual experiments.

Recommendation

Well qualified, well equipped field staff be made available to assist farmers with experimental design and data collection. These field staff should have ready access to basic scientific equipment such as data loggers, scales, plot combines, sampling equipment and laboratory analyses.

*****

7.3 Future Research Topics

Future research topics are identified in a number of locations throughout this report. Presented below is a listing of these research topics. The reader is referred to Section 5 to find the context in which the research need was identified.

These recommendations for future research have not been put in any order of priority. Experience in the TED program has clearly shown that the exercise of assigning priorities to research topics is best accomplished in a workshop setting. In a workshop setting a wide range of people with different disciplines and perspectives can work through a process of establishing consensus on the most important research areas. The initial research priority setting workshop within TED was a two-day affair involving in excess of 50 people. Any major programs designed to follow and build on the SWEEP experience should be initiated with a similar workshop. It is important that the workshop participants be balanced between farmers, researchers and extension personnel, and that the workshop be organized in a way which encourages open, yet structured discussion of research possibilities. This exercise is best structured under the impetus of a new, emerging program as the first step toward implementation.

7.3.1 Soil and Water Quality

- establishment of parameters and methods of measurement which will define water and soil quality in a way which will enable monitoring of progress toward sustainable agriculture objectives. These parameters should be capable of base line definition against which progress can be measured.
- investigation of soil cracks in clay soils as a direct route for water movement from the soil surface to field tile and the implications of this for water quality.
- evaluation of the environmental impacts of the use of manure in reduced tillage and where manure is not incorporated;
- reconsideration of existing codes of practice;
- evaluation of flow control measures in lowland clay soils, where tile drainage waters are retained and reused rather than discharged to ditches;
- evaluation of recommended conservation farming measures to ensure they address both soil productivity and water quality issues. The implication of TED research showing significant P loadings to streams without significant sediment loss is that control measures aimed at reducing the amount of P delivered to Lake Erie may be less effective than initially predicted; and

- examination of the relative impacts of various forms of P on Lake Erie; research has raised the possibility that conservation farming practices may alter the short term dynamics of the P cycle both on the cropland and in the water. The impact of this possibility on the goal of improved water quality in Lake Erie should be investigated.

7.3.2 Farm Management

- assessment of the Farm Decision Support Framework in a real farm context and development of the system as a learning tool to explore the implications of farm management while making use of farmer experience and data; and
- development of management systems which will work with intrinsic soil properties to optimize the relationship between crop yield and crop input on fields with variable topography.

7.3.3 Soil Fertility

- development of the use of the soil nitrogen test for predicting nitrogen fertilizer requirements in conjunction with nitrogen fixing crops;
- development of the use of the nitrogen soil test to determine the merit of splitting nitrogen application between planting and sidedress, and to establish the extent to which there is a requirement for more nitrogen at planting under conditions of higher residues;
- evaluation of the role of cover crops in nutrient cycling particularly in systems where nutrients are in excess of crop requirements; and
- evaluation of the capacity of cover crops to prevent leaching and runoff losses of nitrates.

7.3.4 Residue Management

- confirmation of the method to predict corn cold temperature tolerance with field tests in Ontario to corroborate the observed relationship between the index of root or coleoptile growth and cold tolerance of corn hybrids;
- development of research methods to examine the dynamics of residue decomposition with respect to biological, chemical and physical responses; and
- examination of the links between residue decomposing organisms, organic products of decomposition and their response to the soil environment in the context of the impacts on crops;

7.3.5 Tillage Practices

- development of an inexpensive field measurement of soil compaction which a farmer could use to determine whether a severe compaction problem exists, and where remediation will produce a favourable response. This may be as simple as promoting regular inspection of soil profile conditions looking for structural changes which indicate compaction.
- development of guidelines to indicate conditions under which tillage operations will or will not result in compaction.

8. LIST OF REFERENCES

The following is a list of references which do not appear in the references section of the literature review (Appendix G).

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APPENDIX A

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APPENDIX B

Workshops

The following is a brief summary of the workshop and conference events conducted under the TED program. These events added to the development of the program and its delivery of the program to its participants and the public in general. The initial planning workshop which set out the priorities and topics for the research program is not discussed here since it is presented fully in the main body of this report.

Farmer Workshop, March 10, 1988, London, Ontario

A farmer workshop was held to present the findings of the 'Farm-Based Research and Development Survey' to the participants in the survey. Ecologistics Ltd., the contractor that carried out the survey, summarized the farm management practices characteristic of the surveyed leaders in the conservation farming community. The major concerns, and hence, opportunities for TED research, in the area of conservation farming, were highlighted. Further discussion of this particular component of the survey findings was held with the workshop participants to set specific objectives for the research topics outlined in the TED 5-year plan of research.

Discussion groups were formed around the question of the ways in which TED research could involve farmers. Participants presented their ideas on the opportunities and limitations for involvement in the research to TED management. Participants were made aware of contractual requirements in carrying out research, and were provided with guidance on how to form groups and bid on research contracts.

TED Modelling Workshop, November 14-16, 1988, Guelph, Ontario

A workshop was held during the end of the first full year of research under the TED research plan. Its purpose was to review and refine a conceptual model to aid in interpreting the effects of current, likely, and possible farming practices on field losses of soil, nutrients, and pesticides, and on farm financial performance. Components of the conceptual model which were addressed within TED were identified, and research priorities in light of the conceptual model were re-evaluated during a systematic ranking exercise.

Workshop participants included farmers, researchers, and government agency representatives. Participants developed a model in which the effects of farm management actions (tillage, crop type/rotation, weed control, water management) on a number of valued resources (nutrients, topsoil, yield, revenues, labour, chemicals) were considered. The variables considered when evaluating effects of farm management actions were: technology available, soil type, prices of crops, inputs and capital, topography, weather, attitudes, assistance programs, degree of land tenure, geographic location, and land class.

TED Conference, March 27-28, 1990, Guelph, Ontario

A midterm conference served to update interested individuals in what was ongoing in TED. It consisted of visual presentations (posters) to familiarize contractors with the research of other contractors, to present research results to TAP, and to permit the farm community and government personnel to review and discuss TED research. Two panel discussions (focusing on upland and lowland farm management scenarios) explored the application of various technologies tested under TED in a range of farm management situations.

The discussion was organized using simulated farming situations to explore interrelationships between and among the various technologies and farming systems.

TED/Tillage 2000 Conference, March 5-6, 1991, London, Ontario

A joint effort between the two research-based subprograms of SWEEP was held at the conclusion of the Tillage 2000 program and near the end of TED. The conference was to allow farmers, government, industry, and university experts to review the results of on-farm research conducted under TED and the Ontario Ministry of Agriculture and Food's Tillage 2000 program.

TED and Tillage-2000 researchers presented their findings under one of several subject areas: farm management systems, cropping strategies, tillage options, fertility management, water management, and pest control. Discussion and questions followed the presentations. Additional research results were displayed on posters which complimented the presentations and allowed observers to explore the research more fully and discuss the work with those responsible.

Feedback from the conference indicated that farmer oriented programs, such as TED and Tillage-2000, should be continued or followed by similar programs. Participants felt that meetings such as this conference are extremely valuable in forging links between farmers and researchers.

APPENDIX C

Farm Producer Participation in TED Research and Surveys

Farm Producer Participation In TED Research And Surveys						
First	Last	City	County	Code [1]		
David	Ainslie	Comber	Essex	C		
Doug	Albin	Paris	Brant	C		
Roy	Anderson	Dover Centre	Kent	C		
Lawrence	Andres	Tiverton	Bruce	S		
Lloyd	Arnold	Dresden	Kent	C		
Ken	Baechler	Rockwood	Wellington	C		
Paul	Barrette	Belle River	Essex	C		
Ray	Basima	Aylmer	Elgin	W		
Ron	Beaton	Ridgetown	Kent	C		
Ken	Bee	Dresden	Kent	C	W	
Larry	Bender	Tavistock	Oxford	C		
Darrel	Betts	Glencoe	Middlesex	C		
Albriecht	Bienzle	Harrow	Essex	C	W	
Burns	Blackler	St. Marys	Perth	W		
Charlie	Bolton	Mt. Bridges	Middlesex	C		
Mike	Bontje	Thorndale	Middlesex	W		
Brock	Bradley	Paincourt	Kent	C		
Gordon	Brooksbank	Dresden	Kent	W		
Elias	Brubacher	Mt. Forest	Wellington	C		
Leroy	Bryan	Granton	Middlesex	C		
Doug	Buchanan	Tilbury	Kent/Essex	C		
Bernard	Calhoun	Essex	Essex	C		
Robert	Chauvin	Pointe-aux-Roches	Essex	C		
Robert	Chesney	Innerkip	Oxford	C		
Gary	Chipps	Delhi	Haldimand-Norfolk	C		
Gary	Chittle	Maidstone	Essex	W		
Dick	Cieslar	Wyoming	Lambton	W		
Don	Cleave	Norval	Peel, Waterloo	C		
Paul	Courey	Tilbury	Essex	S	W	
Bill	Couture	Blenheim	Kent	C		
Peter	Cumming	Blenheim	Kent	C	W	
Bob	deBrabandere	St. Marys	Perth	S	W	
Rick	deBrabandere	St. Marys	Perth	W		
Henri	deBrower	Blenheim	Kent	C	W	
Mike	deBrower	Blenheim	Kent	W		

Farm Producer Participation in TED Research And Surveys						
First	Last	City	County	Code [1]		
Hector	Delanghe	Blenheim	Kent	C		
Ted	Delstra	Petrolia	Lambton	W		
Bill and Agnes	Denham	St. Marys	Perth	W		
Eric	Devlaeminck	Lucan	Middlesex	C	W	S
Adrian	Dielman	Thamesville	Kent	W		
Don	Dotzert	New Hamburg	Perth	S		
Murray	Doyle	Merlin	Kent	C		
John	Droog	Thorndale	Middlesex	C		
Lou	Eckert	Stratford	Perth	W		
Scott	Elliot	Corunna	Lambton	W		
Bernard	Eyraud	Maidstone	Essex	W		
Robert	Farquarson	Tilbury	Kent	C		
Wayne	Fear	Brussels	Huron	W		
Brian	Fletcher	Komoka	Middlesex	S		
Chuck	Ford	Zurich	Huron	C		
Ross	Gammie	Ariss	Wellington	C		
Ken	Gascho	Zurich	Huron	C		
Joe	Gerber	Millbank	Waterloo	C		
Bill	Gillanders	Wheatley	Essex	W		
Doug	Glenn	Thedford	Middlesex	C	W	
Dean	Glenney	Dunnville	Haldimand-Norfolk	C		
Joe	Gorski	Harrow	Essex	C		
Tony	Gosnell	Iona Station	Elgin	W		
Charlie	Grant	Wilkesport	Lambton	S		
Herb	Groenewegen	Blenheim	Kent	C		
Harold	Hall	Essex	Essex	W		
Bob and Don	Hart	Woodstock	Oxford	S		
Ron	Hayho	Aylmer	Elgin	W		
Allan	Hedley	Canfield	Haldimand-Norfolk	C		
Ray	Hogan	Lucknow	Huron	W	S	
James and Lorraine	House	Port Stanley	Elgin	C		
John	Hoy	Merlin	Kent	C		
Arthur	Huffman	Blenheim	Kent	C		
Robert and Glen	Jack	Chatham	Kent	C		
Murray	Jack	Chatham	Kent	C		

Farm Producer Participation in TED Research And Surveys						
First	Last	City	County	Code [1]		
Peter	Johnson	Lucan	Middlesex	W		
Paisley	Johnson	Tara	Wellington	S		
Bruce	Johnstone	Chatham	Kent	C	W	
Mint	Klynstra	Ingersoll	Oxford	C		
Bill	Krestel	Pelee Island	Essex	C		
John	Lammers	Petrolia	Lambton	W		
Gerard	Lanoue	Stoney Point	Essex	C	W	
Ray	Light	Aylmer	Elgin	W		
Frank	Little	Woodslee	Essex	W		
Jamie	Littlejohn	Wallacetown	Elgin	W		
Murray	Lobb	Clinton	Huron	C	W	
Gordon	Lobb	Clinton	Huron	C		
Don	Lobb	Clinton	Huron	C	S	W
Reg	Lumly	Sarnia	Lambton	W		
John and Hugo	Maaskant	Clinton	Huron	C	S	
Mac	MacRae	Alvinston	Lambton	W		
Gerry	Mailloux	Comber	Essex	W		
Bob	Mailloux	Tilbury	Essex	S		
Quentin	Martin	West Montrose	Waterloo	C		
Richard	McCracken	Melborne	Middlesex	C		
Ron	McEwen	Wyoming	Lambton	W		
Jack	McGregor	Clinton	Huron	C	W	S
Walter	McIlwain	Goderich	Huron	W		
Dave	McIntosh	Brownsville	Oxford	C		
Bernard	Meyer	Belmont	Middlesex	W		
Don	Miltenburg	Lucknow	Huron	W		
Hermas	Moison	Belle River	Essex	C	W	
Lloyd	Moore	Ayr	Brant	S		
Brian	Moore	Lucan	Middlesex	C		
Jim	Murison	Markham	York	S		
Dave	Murray	Iona Station	Elgin	W		
Dave	Murray	St. Pauls	Perth	W		
George	Murrell	Thornedale	Middlesex	W		
Dan	Myslik	Blenheim	Kent	C		
Stuart	O'Neil	Denfield	Middlesex	C		

Farm Producer Participation in TED Research And Surveys						
First	Last	City	County	Code [1]		
Garfield	Parry	Chatham	Kent	C		
Doug	Parry	Chatham	Kent	C		
Mark	Parry	Chatham	Kent	C		
Arpad	Pasztor	Port Burwell	Elgin	C		
Chuck	Pegg	Morpeth	Essex	C		
Brant	Pilkington	Melborne	Middlesex	C		
Gerry	Poechman	Walkerton	Bruce	S		
Clinton	Pottruff	Paris	Brant	S		
Jeff	Quinn	Salford	Oxford	C		
Dave	Reibling	Tavistock	Oxford	C	S	
Harry	Reipma	Dresden	Kent	W		
Max	Ricker	Dunnville	Haldimand-Norfolk	S		
Wilf	Riddell	Granton	Middlesex	W		
Jack and Donna	Rigby	Blenheim	Kent	C	S	W
Mel	Ritchie	Lucknow	Huron	W		
Kevin	Rivers	Beachville	Oxford	C		
Vernon	Ruby	Shakespeare	Perth	C		
Carl	Ruby	Shakespeare	Perth	C		
Wiley and Barbara	Rycquart	Straffordville	Elgin	W		
Harold	Saunders	Denfield	Middlesex	C		
Carl	Schlegel	Shakespeare	Perth	C		
Jim	Scott	Lucan	Middlesex	W		
Bruce and Delores	Shapton	Exeter	Huron	C		
Charlie	Shelton	Ingersoll	Oxford	S	C	
Bruce	Shillinglaw	Londesboro	Huron	C	S	
David	Siddal	Ilderton	Middlesex	C		
Maurice	Skinner	Strathroy	Middlesex	C		
George	Skinner	Strathroy	Middlesex	C		
Brian	Skipper	Tilbury	Kent	C	S	
Doug	Smith	Thamesville	Kent	C	W	S
Ross	Stokes	Dover Centre	Kent	C		
Lawrence	Taylor	Londesboro	Huron	S		
Wayne	Tebbutt	Clinton	Huron	C		
George	Thompson	Clinton	Huron	C		
Robert	Thompson	Clinton	Huron	C		

Farm Producer Participation in TED Research And Surveys						
First	Last	City	County	Code [1]		
John	Van Dorp	Woodstock	Oxford	C		
Hank	Vander Pol	Blenheim	Kent	C		
Elwin	Vince	Merlin	Kent	C		
Martin	Vink	Fullarton	Perth	C	W	
Robert	Vriesaker	Woodslee	Essex	W		
Gerhard	Weber	Thorndale	Middlesex	C		
Don	Weeks	Glencoe	Middlesex	C		
Felix	Weight-Beinzel	Harrow	Essex	W		
Jeff	Wilson	Charing Cross	Essex	C		
Reid and Rhonda	Wilson	Newton	Perth	W		
Stanley	Wonnacott	Chatham	Kent	C		
Bob	Wood	St. Pauls	Perth	C		
Wayne	Woods	Dashwood	Huron	W		
Richard	Yantze	Tavistock	Perth	W		
Denis	Zettler	Wallacetown	Elgin	W		

1 **W** = Weed Survey Participant; **C** = Research Cooperator; **S** = Conservation Farm Practices Survey Participant

APPENDIX D

Awarding and Monitoring of Research Contracts

AWARDING AND MONITORING OF RESEARCH CONTRACTS

AWARDING RESEARCH CONTRACTS

Considerable valuable experience was gained during TED in the process of identifying the specific objectives of research projects, writing statements of work to reflect these objectives, and soliciting and evaluating proposals to conduct research which addressed the identified objectives. There were three main criteria considered when evaluating research proposals under the TED program:

1. to make use of the best available expertise and experience as evidenced by the scientific validity of the proposed research design and the qualifications of the research personnel;
2. to assist in the development of a broad base of expertise in agricultural science and technology development; and
3. to maximize the involvement of farmers in the research and derive the greatest benefit possible in terms of technology transfer and high profile demonstration of valuable farming technologies.

Irt addition to these three important criteria the evaluation and awarding of research contracts under TED was subject to the policies, regulation and control of Supply and Services Canada. Attempting to give due consideration to the three criteria outlined above and to function within the policy of Supply and Services Canada, while still ensuring that research was done by the most qualified people in the most cost-efficient way, required some innovative approaches to the process of preparatior of Request for Proposals (RFPs) and evaluation of the subsequent response. Early in the process it became evident that the TED Subprogram had three main sources of expertise:

- the farming community;
- the scientific and academic community represented by researchers in universities and colleges across the province; and
- scientific and technical expertise residing in private sector consulting firms.

Each of these three sectors - private consultants, government-supported scientists and practising farmers - have definite strengths and offer differing benefits to the TED Subprogram. Very specialized scientific expertise is usually confined to the government-supported institutions, while highly developed project management skills and flexible service capabilities are strong characteristics of the private sector consultants. Southwestern Ontario is also fortunate to have a core of world-class innovative farmers who have the ability to deal with scientifically rigorous studies and yet also have the pragmatic viewpoint necessary to evaluate the potential use and effectiveness of the technology in the wider farming community. In addition to the small core of conservation farming leaders, there is a wider segment of the farm population keenly interested in, and quite capable of participating in, the development and evaluation of conservation farming technologies.

The above considerations and requirements led to the formulation of a two-track approach to awarding research contracts. Wherever possible the Statements of Work were written and the Requests for Proposals were circulated so as to facilitate and, if possible, require a high degree of cooperation among farmers, scientists and private consultants. Where such an arrangement was not feasible, or for some reason undesirable, a decision was made as to which of the specialized sectors was best suited to conducting the particular research. Once this decision was made the Request for Proposals were directed to that sector.

This procedure helped to ensure that the research dollars available to the TED program were spent in the most efficient manner and produced scientifically valid results of maximum practical use to the farmer. In addition, this approach allowed for the development and growth of private sector expertise in agricultural science and technology development. This approach was used, with varying degrees of success, over the length of the program.

MONITORING RESEARCH CONTRACTS

The monitoring of research projects was conducted with two main objectives in mind:

1. to obtain information on the progress and management of the research project in relation to budget and schedule requirements and objectives of the research; and
2. to gather information pertinent to the evaluation of the research project and indicative of the scientific validity of the results of the research project.

The basic strategy involved review of the project at critical stages in its progress. A detailed work plan was reviewed with the researchers shortly after the project was initiated.

Where applicable, field visits were made to the research sites at several stages during the growing season: during planting; at critical stages of growth; and, at crop maturity or harvest. For certain projects, visits were made at critical seasons for water movement, such as spring melt. The approach to monitoring projects was kept flexible in order to allow response to unforeseen problems.

The type of information gathered in the monitoring process included:

a) progress of the project in relation to its schedule and research objectives;

b) departures from expected research progress;

c) various evaluative information including,
   - experimental design and strategy, plot layout and orientation;
   - scientific validity, replications, statistical validity and control of nonmeasured variables;
   - the quality and timing of agronomic operations performed in the experiment, such as the quality of seedbed preparation, precision of placement of seed and fertilizer, weed control, etc.;
   - data collection techniques, including condition and calibration of instruments and agricultural equipment such as planters and sprayers;
   - harvesting techniques, yield measurements and record keeping;
   - involvement of senior scientific personnel and quality of technical operations; and

d) where experiments were conducted on farmers; fields, farmer interest and involvement as well as problems encountered and how they were handled were noted.

Where necessary corrective action was taken to ensure the projects were completed on schedule and on budget.

APPENDIX E

TED Research Summaries

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E.1 FARM MANAGEMENT SYSTEMS

E.1.1 A Review of Farm Based Soil Conservation Research and Development

(SWEEP Report No. 2)

Introduction

One of TED's earliest projects involved a survey of conservation practices being tested and adopted by leading farmers in Ontario. The study carefully tabulated the reasons why certain technologies were chosen and identified field level problems, many of which were later addressed by TED research.

Study Approach

A total of 27 farmers in 12 counties were included in the study. Five of these were engaged in organic farming systems. They were chosen on the basis of demonstrated experience in the implementation of conservation practices or technology as part of their overall management system. Selection also emphasized contact with the earliest users of new conservation techniques.

Each farm operator completed a detailed questionnaire and participated in an interview which examined their use of conservation practices and related problems.

Major Findings

The threat of soil erosion and soil degradation was the primary reason for the adoption of new technologies. Economic reasons were also key to the implementation of conservation practices.

A variety of research needs were identified in the survey. Specific research recommendations including weed control in conservation tillage systems and cover crop rotation were given a high priority in TED's research program. Information on conservation tillage/planting equipment and farm management systems was also a priority concern among those surveyed.

The survey participants shared a desire for increased opportunities for communication and information exchange among farmers experimenting with new conservation systems. A key component of TED's research mandate was the expansion of the network of farm cooperators. This has been achieved through an emphasis on active farm-level involvement in TED research activities.

Follow-Up Workshop

After the results of the survey were compiled, the study participants were assembled for a workshop in which the study findings and research priorities were discussed as a group.

The workshop also examined ways in which the farm community might get involved in TED's ongoing research program. There was support for the direct involvement of farmers in TED research on a cooperative basis. Links between the farm and research community were discussed.

The farmers research support needs, as described in the workshop, include technical assistance in research design, reporting and project administration.

This project and the follow-up workshop played an important role in shaping the direction of the TED research which followed it.

E.1.2 Management of Farm Field Variability

(SWEEP Reports No. 38, 45 and 46)

This project arose out of the identified need to better understand the challenges involved in managing farm fields with complex topography, soils and drainage patterns. The overall objectives of the farm field variability project were:

1. to quantify soil movement in complex topography typical of the upland regions of southwestern Ontario;
2. to determine the relative rates of soils erosion and phosphorus delivery on various landscape positions under different tillage systems;

4. to establish the extent to which conservation farming systems will reduce erosion on shoulder slope positions;

5. to relate variations in crop yield to intrinsic soil properties;

6. to determine the relationship between variations in crop yield and soil landscape variability under different tillage systems; and

7. to provide a basis for subsequent development of strategies to manage farm field variability under different soil conditions and farm systems in southwestern Ontario.

The project was conducted in cooperation with the Tillage 2000 program. Tillage 2000 was a long-term on-farm field-scale research and demonstration project conducted for five years on up to 40 farms across the Province of Ontario. Each site included a carefully controlled and laid out research plot in which conventional and conservation farming systems were compared to each other through the use of a number of permanently located sample points occupying the same soil landscape positions. This network of study sites provided valuable research opportunities for the TED program and the TED funding allowed Tillage 2000 to conduct more detailed analysis of the soil movement within the sites.

The farm field variability research also built upon a study by L.S. Crosin and R.K. Protz of the University of Guelph. In 1972, Crosin and Protz sampled 180 soil landscape positions in a 10 m x 10m grid. The soil cores were stored. Part of the farm field variability project of TED involved resampling this site in 1987 and analyzing the soil samples for ^{137}Cs. The ^{137}Cs in soil comes from atmospheric deposition (fall-out) from above ground nuclear testing in the early 1950s and 1960s. The ^{137}Cs does not naturally occur in soil, but when added to soil it binds tightly and is not leached or taken up by plants to a significant extent. The ^{137}Cs deposited by the atmospheric deposition was subsequently mixed evenly in the plow layer by tillage. Thus, the movement (losses or gains of ^{137}Cs in a landscape is caused by the movement of soil.

The ^{137}Cs landscape study indicated that the total field scale soil loss in complex topography was relatively minor as most of the soil eroded from the convex upper slopes areas was simply deposited in the concave lower slope areas. This study found that soil loss on shoulder and crest slope positions can be greater than 100 tonnes per hectare per year, confirming earlier observations by Battiston and Miller, University of Guelph, that these are areas of severe erosion. The major conclusion of this portion of the farm field variability study is that water erosion is not the major process responsible for soil movement in complex topography. The conclusion calls into question the commonly held assumption that crop productivity losses from soil erosion and the environmental effects of soil erosion are directly linked. This project demonstrates that significant soil redistribution is occurring within complex fields which is not related to the off-field transport of sediment, phosphorus and other chemicals. Serious yield problems can arise on such fields independent of serious water quality problems in associated watercourses.

The second part of the farm field variability project examined the processes responsible for the severe erosion on upper slope landscape positions. ^{137}Cs readings of paired plots were used to compare soil translocation by upslope and downslope tillage. The single sequence of conventional tillage operations consisting of fall moldboard plow, spring tandem disk and C-tine cultivator was found to move significant quantities of soil in the direction of tillage. Assuming equal amounts of the upslope and downslope tillage, it is estimated that the net effect is 20 kg of soil moved downslope for each metre of slope width. If tillage operations occur upslope equally as often as downslope, the average annual soil loss over the convex slope is estimated to equal 67 tonnes per hectare.

The significance of the conclusion that soil loss by tillage translocation is an order of magnitude higher than soil loss by water cannot be overstated. Soil loss by tillage will occur to some degree on all convex slope positions in all regions with complex topography. The validity of all soil loss and erosion estimated using any form of soil tracer such as ^{137}Cs are questionable unless the changes are known throughout the landscape. Predictive soil loss and crop productivity models that do not include the process of soil loss by tillage will not represent reality for cultivated land in complex topography and will have little predictive value. Preventative and remedial managements which do not control tillage soil loss will have little value in maintaining or enhancing soil quality.

Another component of this study used the ^{137}Cs to estimate soil and phosphorus losses under different tillage systems. A subset of approximately 400 benchmark locations were selected from the Tillage 2000 project.

The method of estimating soil loss from ^{137}Cs is well known and used throughout the world. However, the method assumes that a relationship exists between the loss of cesium at a particular site and the amount of net soil loss. For water and wind erosion there is usually little deposition on upper, and mid-slope positions. Thus, cesium and soil loss should be related. However, as another component of this project has shown, tillage translocation of soil is a major process redistributing soil in complex topography. This process results in significant lateral mixing of soil/cesium. The net effect is that cesium

translocation of soil is a major process redistributing soil in complex topography. This process results in significant lateral mixing of soil/cesium. The net effect is that cesium loss at a particular soil landscape is not necessarily related to soil loss. Thus, in the absence of a good mechanistic model or understanding of tillage translocation, only a full mass balance of cesium in the landscape can be used to estimate soil loss.

Unfortunately, the Tillage-2000 benchmarks were not established to monitor the full three dimensional landscape. Only a cross-section of the landscape was used. This is an efficient methodology to examine landscape effects on yield, water erosion and soil properties under different tillage systems, but not for a full mass balance of cesium.

The moldboard tillage system resulted in considerably more change in ^{137}Cs (1987 to 1990) than either minimum or no-till systems.

Table 1. Average Soil and Phosphorus Losses

(estimated from all T-2000 sites sampled)

	Moldboard	Minimum Till	No-Till
Soil (t $ha^{-1}yr^{-1}$) loss	60.0	30.0	0.0
Phosphorus (kg P ha^{-1} yr^{-1})	40.0	20.0	0.0

The minimum-till average loss values are not a good indication because most of the loss occurred on two sites. For nine out of the eleven minimum-till sites soil and phosphorus loss was negligible. On one minimum-till site the loss was excessive which probably is the result of poor mass balance rather than an actual loss. These estimated losses are based on the assumption that the average ^{137}Cs loss from the benchmarks is representative of the mass balance of the entire field.

Average ^{137}Cs losses from specific landscape positions were quite variable, with large losses generally observed on shoulder/crest slope landscape positions. Soil losses from these landscape positions were very large, in many cases exceeding 100 t ha^{-1} yr^{-1}. The variable nature of the losses (or gains) is consistent with the study by Battiston *et al.* (1987) and the other components of this project.

The last component of this project was conducted to determine crop yield response to different tillage systems, at different landscape positions, and relate the variations in crop yield response to soil and landform properties. The possibility of implementing variable management was examined by quantifying the stability of the yield response pattern over a number of years.

Field sites were selected from the existing Tillage-2000 sites for detailed examination of the relationships between landform, soil properties, soil loss, tillage management and crop yield. At each field site, two tillage systems (conventional and conservation) were established and permanent benchmark monitoring locations selected. The conservation system was defined as any tillage system which should decrease the loss of soil from the field by erosion. The tillage systems were classified as:

- no-till if no primary or secondary tillage was used;
- minimum till if no inversion tillage (moldboard plow) system was used; and
- moldboard if a moldboard plow was used to invert the soil.

Landform at each benchmark was characterized by a detailed elevation survey and a digital elevation model and classification system.

Relative soil loss was obtained from relative changes in ^{137}Cs content (a naturally occurring soil tracer) measurements. Soil properties were obtained from a 1.0 m soil core taken at each site using an hydraulic soil sampler. Yield measurements collected as part of the Tillage-2000 program were entered into the data base containing all of the other information. Soil sampling for soil fertility analysis was also completed. Indices for plant available water and air filled porosity were calculated from soil profile data.

The five-year (1986-1990) average gain corn, soybean and small grain yields in the paired conservation and conventional tillage systems were not significantly different. In addition, field by field, and year to year differences in yield were equally variable in the conservation and conventional systems. The paired moldboard and minimum-tillage sites suggest a slight yield advantage to the moldboard system. Average relative crop yields across all crop types were higher in the moldboard system for all years except 1988. A total of 23 of 36 plot years had higher yields on the moldboard system compared to the minimum tillage system.

The paired no-till and moldboard tillage sites indicated no significant difference in yield for any of the crop types. A total of 14 of 23 plots years had a higher yield in the no-till system than in the moldboard system. Average relative yield across all crops was higher in 1987 and 1988 in the no-till compared to moldboard, but lower in the other three years.

The paired no-till and minimum tillage sites indicated a slight yield advantage to the no-till system. The average no-till yield was significantly higher than minimum tillage yield (0.1 probability for both the soybeans and small grain crops).

Soil texture (Ap horizon) class and tillage times texture class interactions were significant (0.001 probability) in explaining the variations in yield of all crop types. Analysis indicated that for percent sand contents greater than 36% the no-till yield would, on average, be higher than the conventional tillage system. The no-till yield for finer textured soils would, on average, be lower than conventional tillage systems. The interaction of tillage and texture is suggested as the reason for little overall differences in tillage system on crop yield, across all farm sites.

A subclassification by upper, middle and lower slope position within each of the original landform classes explained a significant (0.05 probability) amount of the variability of almost all soil properties, especially those related to soil loss. The conceptual model of the slope location of the original landform classes was correct for approximately 60-70% of the benchmarks. However, a significant number of benchmarks were found at slope positions not conforming to the conceptual model. The poor success of the original seven landform classes in explaining the spatial variations of soil properties was attributed to the conflicting patterns that water flow and tillage translocation would have on soil properties.

Solum depth was significantly related to soil texture class, but ^{137}Cs content was not related to texture. This suggests that the amount of soil loss is not related to texture, and the increased solum depths in the sandy soils are related to pedogenic processes. The independence of soil loss on soil texture, and the higher cesium loss on upper slope compared to middle slope positions are contrary to water erosion theory, but consistent with tillage translocation theory.

The difference between the highest and lowest yielding areas in a field, across all years and all sites was 40% of the mean field yield. Tillage system did not significantly affect the within field variations in yields. The lowest, highest and range of relative yield difference were similar in the paired tillage comparisons. The standard deviation of relative yield difference was slightly higher (0.05 probability) in the minimum compared to no-till system.

The percentage of within field variation in yield, which remained constant from year to year, was on average 52% and 56% (significantly different at 0.10 probability) for the conventional and conservation tillage systems respectively. Approximately 3% of the benchmarks had an average yield which was at least 30% less than the average field yield. Another 5% of the benchmarks were between 20% and 30% lower than the average yield.

A paired benchmark analysis on crop response on stress (low yielding) and non-stress (high yielding) benchmarks, in stress and non-stress growing conditions was carried out. It indicated that conservation tillage systems may be more buffered against adverse climatic growing conditions than conventional tillage systems. High yielding areas under conservation tillage dropped only 13.8% in yield during a stress year, compared to 16.5% decrease in the conventional system. Low yielding areas in the conservation system decreased 24% in yield in the stress year, compared to a 31.1% decrease in the conventional system. This benchmark data supported the paired field yield data, which indicated that the ratio of conservation yield/conventional yield was the highest in 1988, a drought stress year.

The data in this project, and in the Tillage-2000 project indicate that it should be possible to implement a conservation tillage system with no loss in yield productivity. This is especially true for sandy textured soils where increases in yield are likely under conservation tillage.

For the range in soil and landform conditions in this report, there seems to be little benefit from adopting a minimum tillage system. No-till yields were equal or better than minimum till and the minimum till was slightly lower yielding than the moldboard tillage. In addition, the work on tillage translocation suggests that secondary tillage, which can sometimes be more intensive under minimum tillage, can result in significant soil loss off of shoulder/crest slope positions. The criteria of 20% or 30% residue cover to control water erosion is meaningless with regard to tillage translocation. Thus, unless a management procedure can be devised to control tillage translocation, minimum tillage can not be viewed as a viable alternative to a moldboard system in a sustainable production system. The minimum till system may control water and soil loss by water erosion, but it will not stop the decline in soil quality and crop productivity in the upland regions.

The study indicates that the sandy soils (>70% sand) are the most fragile of all of the soil types. Soil loss in upper convex slope positions has already resulted in yield losses of 30-40% of the average field yield. The productivity losses are even more severe in years of climatic stress. However, since on average, these soils had a higher yield in no-till than in any other tillage system, there seems little reason for farmers not to adopt the no-till system immediately. The main mechanism of soil loss is tillage translocation, and water erosion is likely to be minimal considering the high infiltration capacities of sandy soils.

Conservation tillage systems appear to be increasing the soils buffering capacity against adverse climatic conditions, particularly drought stress. This is encouraging considering the possibility of increased frequencies of drought stress due to global warming trends. The full extent of the remediating capabilities of no-till is not very well understood and should be the subject of future studies. The remediation may appear to be faster than expected because the massive soil loss from tillage translocation has been stopped in the no-till, but continued in the conventional tillage system. Thus, even if the yield productivity of severely degraded areas is stabilized, it would appear that they have undergone an increase because of the continued decline in productivity of the conventional system. The actual rate of remediation and degree to which it is possible to remediate these areas is unknown, and beyond the scope of this study.

A considerable amount of research activity is currently underway regarding available management. A symposium on this subject will be held at the annual American Society of Agronomy meeting. Other symposia have been held the past few years by the American Society of Agricultural Engineers (ASAE). Most of the activity has centred on development of spatial location sensors and variable application technology. There seems to be little doubt that the technical ability to vary management within the field will be present, the important missing link is the knowledge base to decide what kind of management should be done at each point in the field. The yield data indicates that reasonably consistent patterns of yield are present year after year. Thus, variable management from a cost benefit point of view is necessary. Technology for automatic measurement and recording of yield patterns is available, but more accurate equipment is needed.

The consistent yield differences in the benchmarks from year to year is encouraging, and it is clear that many of the differences are related to soil loss or the effects of soil loss. The sites with very large yield losses are diverging shoulder slope/crest positions as indicated by Battiston *et al.* (1987). This problem can be attributed almost entirely to tillage translocation. The obvious solution is not to till the fields. However, it may be possible to change the pattern of tillage. The necessity of at least alternating the direction of all tillage, including secondary tillage cannot be overstated. The net soil losses from alternating tillage directions is still very large, but much smaller than the loss from a single direction.

Without an accurate method of predicting the soil redistribution from tillage translocation, there does not appear to be much hope in explaining any more than about 40-50% of the spatial variations of soil properties. The same constraint exists for predicting variations in yield response using only landform classification. The alternative is to measure and map yield response directly from year to year and identify sensitive areas from changes in yield from year to year, especially during climatic stress conditions. While it is possible to predict that the areas of high yield loss will likely be the shoulder slope positions, it is not true that all shoulder slope positions have been eroded and thus will have yield reductions.

Findings from this project may be summarized as follows:

1. Large amounts of soil and associated phosphorus are being lost from upper slope crest positions and deposited in lower slope positions in the complex topography of southwestern Ontario.
2. The amount of soil and phosphorus moved within complex fields does not necessarily bear any relationship to the amount of soil and phosphorus delivered to streams. Therefore, the crop productivity impacts of this soil movement can be significantly greater than the environmental and water quality impacts.
3. The greatest portion of all soil movement in fields with complex topography is caused by tillage translocation.
4. Conservation tillage systems are effective in reducing the soil and phosphorus movement within fields with complex topography.
5. Within complex fields, crop yield can be related to intrinsic soil properties such as percent sand content and water holding capabilities.
6. The use of conservation tillage, particularly no-till systems, will not result in yield decreases when properly practised on most fields with complex topography.
7. Minimum tillage systems appear to actually buffer the crop against drought stresses and significantly increase yields in drought years.
8. The existence of relatively consistent crop yield patterns across complex fields suggest that there is good opportunity to develop management systems which will work with intrinsic soil properties to optimize the relationship between crop yield and crop input.

E.1.3 DEVELOPMENT OF A COMPUTER-BASED FARM DECISION SUPPORT FRAMEWORK PHASE 1

(SWEEP REPORT NO. 33)

This project consisted of the design and implementation of a prototype computer-based farm management simulation framework. This framework is intended to be used at the level of the individual farm to examine the impact of tillage and cropping decisions on soil quality, nutrient loss to runoff and farm income. The objective of Phase 1 of the study was to determine whether modelling techniques might be useful to effect the transfer of technology from the scientific community to the farm.

The farm management framework (FMF) was developed by ROBBERT Associates, working with an advisory group of farmers, scientists and farm program administrators. The advisory group had the opportunity to advise the FMF developers on the components of this system and interaction between these components as well as on the usefulness and comprehensiveness of the resulting product.

The structure of the farm management framework is completely documented in the FMF Manual (ROBBERT Associates, 1991). The farm management framework consists of five major components:

- cropping component - represents all aspects of crop production, including soil productivity-crop relationships;
- livestock component - represents all aspects of the production of dairy and livestock products;
- crop and manure balance component - keeps track of the interdependence between cropping and livestock operations;
- equipment component - keeps track of the equipment needed for field operations and its utilization in terms of operator time and fuel; and
- farm finance component - represents the elements of farm income and outlay separately for cropping and livestock operations and a capital expenditures account.

The full hierarchy is shown in Figure E.1-1. The interdependence among the components of the framework is shown in the dependency structure diagram (Figure E.1-2).

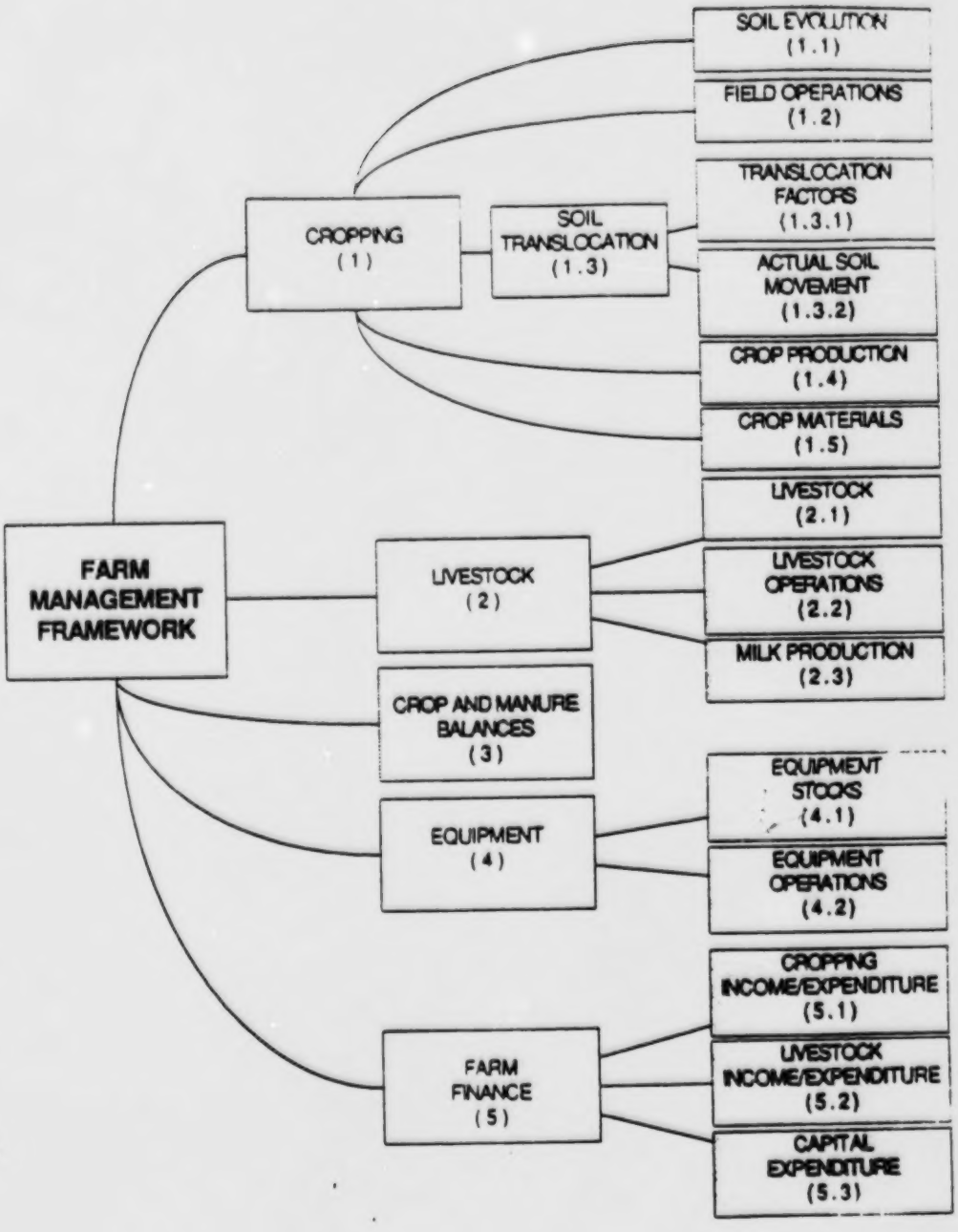
The framework will simulate the economic, agronomic and ecological consequences of a farm management program up to 50 years from the present. This long timeframe was deemed important to evaluate changes in physical parameters, such as soil organic content which change very slowly in response to farm management. All calculations are performed with a one-year time step.

The FMF focuses on the farm as the unit of analysis. A farm consists of a number of fields, stocks of equipment and livestock. Each field is characterized by size, topography, soil composition and topsoil depth. The FMF is generic in the sense that it can be applied or adapted to any specific farm. In effect, a version of the model unique to each farm is generated through the process of calibration, and a history is created which reflects the conditions of the specific farm. The scale of the farm is potentially important in determining the economic viability of the farm.

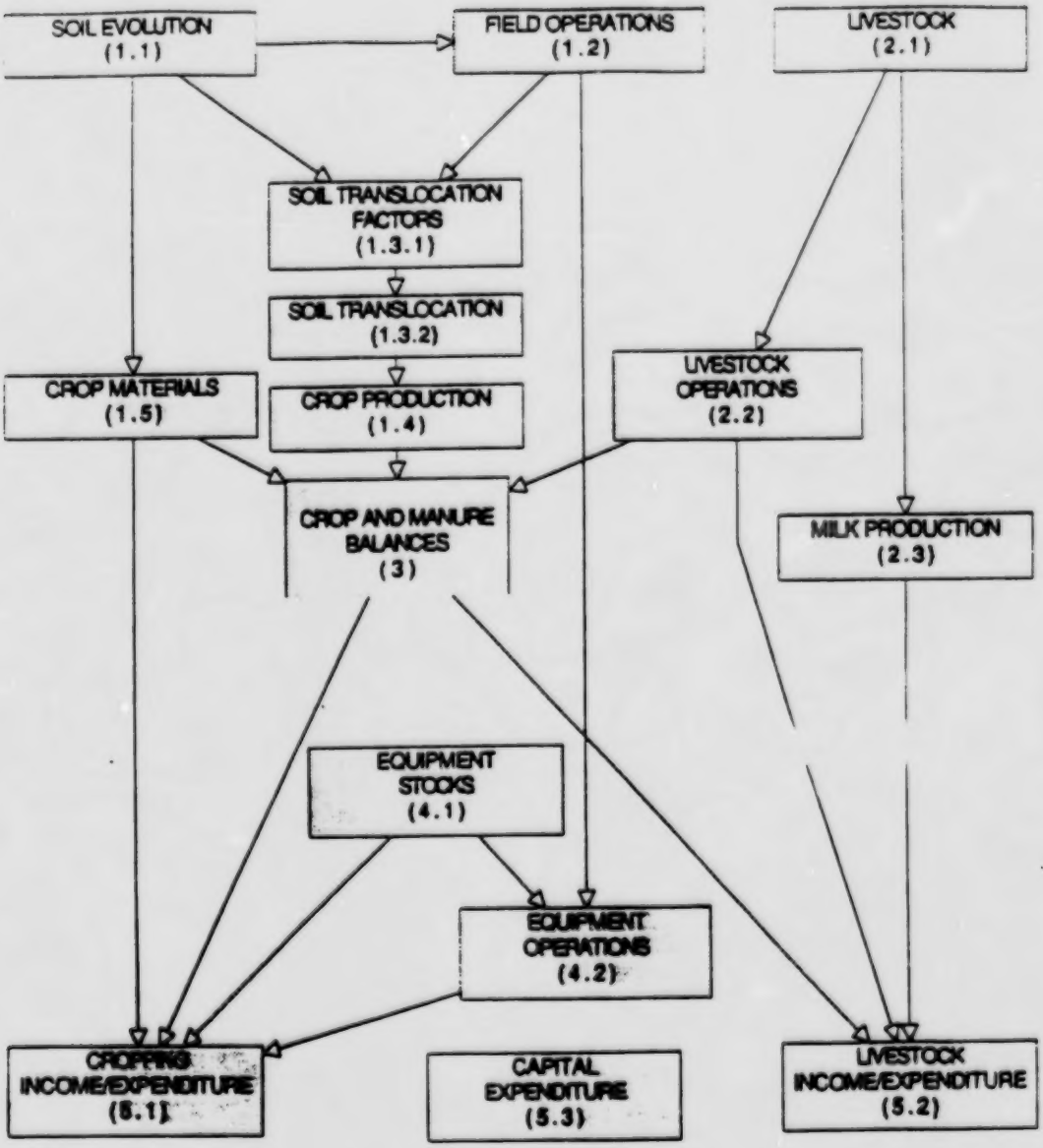
The FMF focuses on the longer term dynamics of farm management. It is intended to support the analysis of alternative farm management strategies. For the purposes of the FMF a farm management strategy consists of a combination of choices with respect to crop rotation, tillage practice and livestock. Each strategy is analyzed in terms of farm income, changes in the soil such as organic content, topsoil depth and productivity and the export of nitrogen and phosphorus from farm fields in stormwater runoff. As a long-term dynamic model, the FMF is based on a number of assumptions regarding management and weather. It is assumed that once the farm management strategy is set, it will be consistently applied and managed over the long term. In other words, the appropriate amount of crop nutrients will be applied as and when required. The impact of extreme weather patterns, such as prolonged drought or excessively wet years are not modelled.

The state of the soil is indicated by its composition by dry weight of sand, silt, clay, coarse fragments, fresh organic content and humic organic content, all measured in kg per kg of soil at the end of each growing season. The act of dynamic soil component is the organic content. The soil evolution model is a set of linear difference equations that keep track of flows of organic material into and out of four separate pools: above ground residue, residue incorporated into the soil, root material and humus.

An important feature of the FMF is the treatment of soil movement from erosion and cultivation and the resulting yield changes. The FMF includes a soil translocation



E.1-1. Farm Management Framework



E.1-2. Farm Management Framework - Dependency Structure

calculator which is capable of representing soil movement even on fields with complex topography. This was considered important due to recent research which has found severe yield losses from shoulder slopes. Within the model, each field was divided into 10 m squares characterized by topsoil depth, elevation, slope and location relative to other field squares. Soil movement is indicated in terms of change in topsoil depth. The relationship between soil depth and yield is represented as non-linear: once a threshold soil depth has been reached, crop yields will decrease. The rate of soil movement is calculated depending upon the tillage practice, the amount of coverage provided by plants and plant residue and the composition of the soil. The model will adjust soil movement for soils with increased cover due to residue or plants. The soil movement due to cultivation (tillage translocation), rainfall, energy (soil detachment) and water flow (sheet, rill and gully erosion) are explicitly represented within the FMF.

The FMF was implemented on a MacIntosh A/UX microcomputer system. The model was calibrated for an artificial farm, consisting of four 40 hectare fields. Each of the four fields were assumed to have a heavy clay loam soil with 5% organic content. The fields were assumed to have differing topography ranging from flat with a 2% slope through to complex topography with a 4% slope.

Data on crop yields, seeding rates, fertilization rates, plant masses and plant densities were taken from the 1991-1992 Field Crop Recommendations published by OMAF and the Epic model database (Williams, *et al.* 1989), then supplemented by the project team and advisory panel as required. Data on crop and input prices were taken from the Ontario Farm Management Analysis Project by OMAF (1989). Representative data on machine passes by crop type and tillage type were provided by the advisory group as were data on the relative soil movement propensity of various machine types.

Using these data a number of sample runs of the framework were prepared for discussion with the advisory group. These demonstrations and discussions with the advisory group resulted in a number of suggested improvements in the structure of the framework:

1. Separate treatment for nitrogen with a difference equation to keep track of sources and sinks of nitrogen and with plant differentiation;
2. Addition of potassium as a nutrient to be treated analogously to the treatment of phosphorus;
3. Additional equations to keep track of soil water retention properties as a function of other variables in addition to the organic content;
4. Modification of the structure of the yield loss equations to respond to topsoil-subsoil mixing rather than topsoil depth;
5. Introduction of machine speed and all the soil translocation equations;
6. Change measure of residue cover from kg/m^2 to percent cover;
7. Add structure to treat crops with an underseeded crop as a combination of two separate crops;
8. Add a non-linear response in soil movement by water erosion to intensity of rainfall events.

The prototype development in testing led to a number of recommendations for further work. It also led to the general conclusion that this type of a model could be quite useful in allowing farmers to investigate the implications of changes in their farm management strategy. The advisory group agreed that the process of sitting down with the model and thinking through the long-term implications of farm management strategies for farm income, changes in soil conditions and environmental impacts of nutrient losses would be a valuable way for farmers and scientists to share information and learn from each other. It was concluded that further evaluation of the FMF by the scientific community, agricultural policy analysts, farm extension workers and farmers should be conducted. Should this more detailed evaluation warrant further development, two phases of activity were recommended.

Phase 2 of the development of the farm management framework should include the following tasks:

1. Implement the improvements identified in the prototype development;
2. Incorporate more complete and detailed scientific data into the model;
3. Calibrate the model using data from a small number of actual farms.

The structure of the model would allow for rapid input of detailed historic farm management data and assist in the fine tuning of the model so that it more accurately reflects our historic understanding and records of the dynamic processes in the farm system.

After refinement and further testing of the prototype a Phase 3 of the project should be conducted which would establish an appropriate institutional framework to support widespread use of the framework by farmers, scientists and extension workers.

E.1.4 THE USE OF KELP AND MOLASSES IN AERATION TILLAGE SYSTEMS

(SWEEP REPORT NO. 26; PROGRESS BULLETIN ISSUE 7)

The use of kelp and molasses in an aeration tillage system was the second part of a two part experiment. Part one of the experiment (Appendix E.1.5) dealt with a comparison of different tillage and cropping systems. That broad study examined a wide range of farm management options developed by a group of innovative farmers known as the Ontario Biological Aeration Tillage Association (OBATA). The farmers were seeking improved soil quality and reduced erosion rates, while lessening their dependence on off-farm inputs. Some of the experiments in that study compared crop growth and yield from fields tilled with the Aerway®, an aeration tillage device that results in minimum soil disturbance with standard tillage devices (moldboard plow). This study was a secondary component of the tillage and cropping study. It attempted to determine the usefulness of kelp and/or molasses and/or a fertilizer solution within the above system.

Experiments occurred during the 1989 and 1990 growing seasons on two sites at each of two locations where the current crop was soybeans and the previous cover crop was rye. The sites received differing treatment combinations which consisted of aeration tillage and different combinations of a liquid formulation of: "71B fertilizer solution", kelp and molasses to the seed or the foliage of the soybeans at specified time intervals.

The experiment was arranged in a randomized complete block design. Observations taken during the study included soybean plant emergence, soybean plant height, soybean plant vegetative and reproductive stage, and soybean seed yield.

Findings from this experiment may be summarized as follows:

1. No significant difference in the number of plants emerged by twenty-one days after planting.
2. No significant difference in soybean plant height two weeks after planting, or after a single or double foliar application of any liquid formulation.
3. No significant differences were observed in soybean vegetative stages at the first foliar application of any liquid formulation. However, at one of the sites, kelp plus molasses and the 71B solution, was significantly further advanced than the kelp and molasses alone.
4. There were no significant differences in terms of the times at which soybean plant reproductive stage were reached.
5. At one of the sites, a foliar molasses treatment had a significantly lower yield than the treatment consisting of a seed application of kelp, molasses and 71B solution with no foliar treatment.

Overall, the study concluded that the application of kelp, molasses or "fertilizer 71B solution" liquid formulations, singly or in combination, at planting or as a foliar spray, did not significantly affect soybean growth.

E.1.5 EVALUATION OF AERATION TILLAGE SYSTEMS

(SWEEP REPORT NO. 50)

This project was initiated by a group of innovative farmers known as the Ontario Biological Aeration Tillage Association (OBATA). The farmers were seeking improved soil quality and reduced erosion rates, while lessening their dependence on off-farm inputs. To achieve this goal, each OBATA farmer developed a farm specific management system, based on a wide range of farm management alternatives. The components of the OBATA system included aeration tillage, reduced tillage, subsoiling, cover crops, crop rotations, foliar spray applications (kelp, molasses and fertilizer) and reduced application rates of herbicides and fertilizers.

A consultant was contracted to work with the farmers in order to evaluate the OBATA system and to compare it with "standard" farm management systems. The "standard" system was the system the farmer had used before becoming involved with OBATA. The study was initiated in 1989 on seven farms, located in Oxford, Elgin, Haldimand-Norfolk and Waterloo Counties. Four of the seven farmers remained in the program for the entire three year study period.

The goal of the project was to evaluate the OBATA approach to reducing tillage, chemical inputs and soil erosion while maintaining or increasing net returns. The primary objectives of the research were:

1. to monitor inputs versus outputs and erosion control on standard versus OBATA systems;
2. to tailor the OBATA system to suit southwestern Ontario farming conditions, and thus in turn help to meet SWEEP targets;
3. to study the different components of the OBATA system; and,
4. to analyze the data and report on the relative merits, associated difficulties, and suggested improvements to farm management under the OBATA system or modifications to it.

Both the OBATA and standard management systems varied considerably from farm to farm in terms of crops grown, availability of manure, and rotation of principal crops. At one site, the farmer adopted OBATA methods throughout his farm, thus, it was only possible to examine different OBATA practices (comparison of cover crops, different fertilizer applications, tillage practices and manure applications).

A baseline survey was conducted on both the OBATA and standard treatments at each of the sites in the first year of the study. Included in the survey were descriptions of the soil texture, organic matter, soil structure, permeability, compaction, moisture regime, earthworm abundance, trash cover and soil erodibility as well as microbial activity in the soils. An observation pit was dug for each of the primary treatments to view soil structure. Compaction was assessed through bulk density and penetrometer measurements.

Microbial biomass in the upper 20 cm of soil was assessed annually at benchmark micro-plots on a cross-section of farms, soils and crops to compare biomass in the standard and OBATA management treatments. The micro-plots were marked to allow composite sampling in the same place each spring from 1989 to 1991.

Each spring, field manuals were supplied to the co-operators for recording their equipment type and size, the number of operations performed in the field, and the date of the operation as well as all inputs. Inputs included fertilizer, pesticides, seed, and molasses (sugars) and kelp. Each fall, yields were recorded for each treatment by the farmers using a weigh wagon.

The OBATA program is based on many components that integrate to become a complete package. The study was structured to observe and assess the package with variations occurring only in certain aspects of the program such as the role of cover crops, the need for subsoiling, the need for kelp or sugar and the rate and placement of fertilizers. At most sites there were at least two treatments, one plot of land with the OBATA system of operations and one with the farmer's conventional methods. There was one replication of each treatment per field and the treatments were set up in a randomized fashion within the test field. A split plot design was used to examine specialized aspects (i.e. with and without subsoiling or cover crops) that vary in the OBATA system.

Several additional studies were conducted at selected OBATA farm sites. The role of kelp and molasses in aeration tillage systems were examined in a two year TED study (SWEEP Report No. 26). Rainfall simulations were conducted at some of the farm sites to compare the soil and phosphorus losses from the OBATA treatments with corresponding losses from the "standard" treatments (SWEEP Report No. 54).

A study on the effect of kelp and molasses treatments on soil micro-fauna was initiated in 1989 by Dr. A.D. Tomlin of Agriculture Canada, but was discontinued after one year due to a corn rootworm infestation in the plots. The corn was badly damaged because the experimental design did not permit the use of treated corn seed.

The results of the three year monitoring program are summarized as follows:

Soils

- No significant differences in soil fertility (P, K, Mg, Ca, pH and organic matter) between the standard and OBATA management treatments.
- Vertical penetrometer and bulk density measurements indicated no significant differences in surface soil compaction between the standard and OBATA treatments. Pocket penetrometer readings in the subsoil layer indicated greater compaction in the standard versus OBATA management plots.
- Over the three year period no significant increases in microbial measurements were detected in the OBATA plots when compared with the standard plots. Microbial biomass measurements taken in 1991 were similar to baseline measurements obtained in 1989. Fields with the greatest biomass carbon counts had a history of intensive soil management (i.e. use of manures, cover crops, and kelp and sugar additions etc.).

Crops

- Soybean yields from OBATA treatment plots in 1989, 1990 and 1991 were no different than yields from standard management plots.
- During the first two years, corn yields from OBATA plots were slightly lower than those on standard treatments. In 1991, corn yields on three OBATA treated plots were greater (6%) than the standard management plots.
- Winter wheat yields were greater from OBATA plots than from standard management plots for the one field season and site where winter wheat was grown. The only OBATA practice that had been implemented on the fields at the time was foliar spraying.

Economics

- Records of inputs and returns showed that OBATA practices were economically comparable to conventional practices.

Other

- Soil micro-faunal populations within plots with added kelp and sugar versus standard management plots indicated no significant differences in a one year study.
- At two sites, rainfall simulations indicated that the combination of cover crops with aeration tillage (Aerway®) resulted in reduced soil, sediment and phosphorus losses, compared to the standard (fall moldboard plowed) treatments.
- The use of kelp, molasses and other sugars, and 71B fertilizer solution as a seed and foliar treatment in an aeration tillage system did not significantly affect growth or yield of soybeans, based on a two year micro-plot study. Nevertheless, positive responses to these additives were evident on some of the other field scale treatments.
- Two of the sites showed noticeable yield increases with a kelp, sugar and fish emulsion foliar spray. The yield increases were not significant (due to lack of data points).

The farmer cooperators had differing opinions about the usefulness of the Aerway® tillage tool. Since it does not take much power to pull the Aerway® and it can be pulled in tandem with the planter, it could save farmers money in terms of fuel, equipment and field operations. Under certain field conditions, e.g. abundant weeds, the Aerway® was not effective, as it did not disturb the soil sufficiently to bury or kill the weeds. The Aerway® was also not effective in wet soil conditions, as it led to surface compaction, without the aeration that occurred under drier soil conditions.

The researchers noted that many of the benefits that the farmers hoped to achieve from the OBATA system, such as improved soil quality and structure could not be properly evaluated in a short term study. The most favourable yield results from the OBATA system occurred in the final year of the study, which may indicate that the farmers need a few years to effectively adapt the new practices into their farm management system.

E.2 CROPPING STRATEGIES

E.2.1 CEREAL AND RYEGRASS COVER CROP MANAGEMENT IN SOYBEANS AND CORN

(SWEEP REPORTS NO. 27 AND 52)

Trials were carried out on four sites during the period of fall 1987 to 1989 to examine three cereal species as winter cover crops: fall rye, spring oats, and spring barley, and to compare methods of establishing these by broadcasting at leaf drop, at harvest, or post-harvest tilling and drilling, into soybeans. The basic management techniques with these cover crop species are known and practised and were therefore chosen for this study. The study examined the methods and species in terms of the winter cover provided and the growth and yield of grain corn in the following year.

The plot-scale sites were on farms under no-till management in Middlesex and Huron counties. The soils were dominantly of silt loam surface textures.

The research indicated that winter rye, spring barley and spring oats seeded at soybean leaf drop or at harvest increased soil residue cover when compared to soybean stubble alone, throughout the winter and early spring. Practical considerations of labour, weather, and timing of cover crop establishment for adequate fall growth do not favour the planting of cereal cover crops at or after harvest.

The plot studies provided the following insights to the management of cereals as cover crops:

1. the till and drill method of establishment decreased main crop residue, thereby resulting in significantly less residue than where no cereal cover crop was seeded.
2. residue levels after spring planting decreased on average 30 to 65% from the early spring levels, depending on the site.
3. rainfall simulation prior to corn planting showed that the management had no effect on the loss of sediment from small plots since residue levels were high (50 to 73%).
4. at all sites the amount of cereal dry matter produced was greatest where cereals were broadcast at leaf drop.
5. initially (14 days after planting) emergence of rye plants was higher than that of oats or barley.

Since winter survival of the spring cereals may require tillage or herbicide to eliminate them the following spring, winter survival of spring cereal varieties was examined. Triwell triticale survived the winter. Some of the barley of the Leger and Sophie varieties survived as well.

Since erosion control benefits in no-till may not exist with this system (item 3, above), the choice to use the cereal cover crops may not be practical unless other benefits are accrued. When field scale studies examined the most promising cover crop management in 1990 and 1991, they were tested in a wider range of farm management systems where they may play a role in soil conservation.

The plot scale studies carried out from 1987 to 1989 identified a broadcast at 10% leaf drop in soybeans or at harvest to have potential for providing ground cover and not impacting upon management in the following year. These two different timings were used at different sites with a comparison at each site of barley, oats and no cereal cover. None of the sites carried out fall tillage, and some of the sites did some cultivation in the following spring.

The spring cereal applications provided additional soil cover at some of the sites, but due to the lack of fall tillage at any of the sites, residue levels exceeded 90% on average. There was no advantage to applying any of the cover crops for after harvest cover. There was generally no benefit realized following spring runoff. Residue levels after planting corn were not increased significantly by the cereal covers. Soybean yields in the application year and corn yields the following year were unaffected by the spring cereal covers. The perception of the farmer cooperators was that the spring cereal cover crop system provided very little residue in the spring and there was no benefit to the system, particularly in a no-till management system. The application of seed in-crop resulted in some damage, although with different management this could be overcome. The cost of the seed for this system at the recommended rate varied from $30/ha for bin run seed to $68/ha for certified seed.

In a study comparing seeding rates, barley produced more dry matter than oats and a rate of twice the recommended rate produced more dry matter than the recommended rate. Seeding at half the recommended rate had no impact on the production relative to the recommended rate.

Spring cereals and annual ryegrass were established in corn at second cultivation in another study. Soybeans were planted the following year. The study concluded that the annual ryegrass produced more top growth than barley by late fall in the establishment year. Seed costs of annual ryegrass were $23.25/ha and seeding rates are lower than with the cereals.

E.2.2 Red Clover Cover Crop Studies - The Effect of Time and Method of Control on the Growth and Yield of Corn

(SWEEP Report No. 36)

Over a period of three years, and seven farm field sites, corn growth was studied where it was planted into red clover in no-till, minimum till (chisel plow), and conventional tillage (moldboard plow, cultivate) systems. In six of seven sites, the red clover was developed as an underseeding to winter wheat, barley, or barley/oats mix. In one of the sites, corn followed a 2 year old stand of red clover and grass hay. The sites were located in Huron and Middlesex Counties on loam, silt loam and clay surface soil textures. The objectives of the study were to evaluate the impact of timing and method of killing the red clover in terms of erosion control, and the success of corn which followed.

The red clover kill methods used were either chemical (herbicide) kills in the autumn, early and late spring, or mechanical kills by moldboard or chisel plows, in the fall or spring.

Soil Residue Cover and Erosion Control

In April, before any spring treatments had been applied, all plots where the red clover had been left untouched, had 85% residue cover. The fall chisel plowing had sufficiently high residue levels for good erosion control, ranging from 53 to 59% and one site having as high as 84% residue. The moldboard plow left residues ranging from 2 to 11%.

After corn planting residue levels were variable, but adequate, on the chemical kill no-till plots where the range was 33 to 84%. The moldboard and chisel plow, which was followed by cultivation on some but not all sites, left residue levels of 3 to 26%.

There were somewhat higher levels of ground cover on the spring chemical kill versus the fall chemical kill since the red clover was permitted to grow in the spring. Less frequently, greater ground cover was established by delaying the timing of the chemical kill in the spring.

On four of five sites which provided a comparison between chisel plow and moldboard plow, the chisel plow provided slightly better ground cover.

Erosion control measured using rainfall simulation on limited treatments and sites, indicated that after planting there was more runoff from moldboard and chisel plowed soil than the no-till. Soil loss was reduced considerably (>85%) by the presence of red clover on the soil surface, and phosphorus losses on the plowed soil were 6 to 9 times those of the no-till plots.

Corn Crop

Corn growing where soil had been plowed generally took fewer average days to reach silking although the numbers were statistically supported in only 3 of 7 sites. The greatest lag in the time to silking between chemical and mechanical red clover kill methods was 4 days.

Four of seven sites experienced significantly lower yields from growing corn no-till in red clover residues compared with using either form of plowing. Later spring chemical kill reduced yields more than an earlier April killing at some sites. The size of the reductions in corn yields averaged 11%. In some instances the grain moisture contents were significantly greater in the no-till corn plots than the conventional ones.

It is suggested that herbicide kill of red clover in autumn should provide adequate soil cover for erosion control and may be less likely to suppress corn yields the following year.

E.2.3 Choice and Management of Cover Crop Species and Varieties for use in Row Crop Dominant Rotations

(SWEEP Reports No. 12 and 57a; Progress Bulletin Issue 3)

A series of experiments were carried out during the 1988 and 1989 field seasons to evaluate the management of cover crops in main crops of soybeans, winter wheat, corn, and spring cereals, and in particular within rotations among these. The study involved the cooperation of ten farmers in Waterloo, Wellington, and Oxford counties, where one or two cooperators were involved in any given project. This summary describes the plot scale research trials in addition to the findings of the field scale research which was carried out in 1990 and 1991.

The project is divided into several studies.

Comparison of ryegrass cultivars for interseeding in corn

In this system herbicide is banded on the row and interrow cultivation or rotary hoeing plus cultivation is carried out. Ryegrass is interseeded in corn 5 weeks after corn seeding, at second cultivation, using a grass seeder box mounted on the rear. Four each of an annual and perennial ryegrass species were compared on their relative success in this system.

None of the ryegrass interseedings had an effect on the yield of the corn crop in which it was established. On the site where corn was lower-yielding there was more ryegrass and more weeds because the corn crop was less competitive. In fact, other research has shown the upper limit on corn yield for successful growth of ryegrass, is 10 t/ha grain corn, or the use of corn for silage, or the use of an early maturing variety in order to open the canopy earlier in the fall.

The success of the ryegrass as cover crop is summarized as follows:

- Ellett was the superior variety among the perennial species; Grimalda perennial was the least well adapted for interseeding;
- all cultivars established well;
- the annual cultivars were consistenily good performers with less variation in biomass than the perennial cultivars;
- the seeding rate, which was the same for both perennials and annuals, may have favoured the perennials since annuals are usually seeded at a 40 - 50% higher rate since the seeds are usually larger;
- the biomass produced was relatively low, with a range of 252 to 851 kg/ha in the above ground portion;
- the presence of the ryegrass decreased weed biomass by 50% compared with where the ryegrass was not present - the main effect of the ryegrass was to reduce flushes of annual weeds after the corn canopy opened;
- all ground covers were high since they included the corn residues measured in the fall in addition to the ryegrass;
- percent ground cover did not differ amongst cultivars;

Rye tillage management systems for soybeans

Fall seeded winter rye was eliminated by discing, or plowing, by harvesting the rye prior to discing and or plowing, or by mowing the rye after soybeans were no-tilled into standing rye ("no-till, mow-kill"). The site was planted to soybeans and evaluated. Nitrogen fertilizer was added to the rye in the spring of the second study year since in the first year rye biomass was small due to insufficient fertility. The harvested rye had better digestibility when harvested in late May, rather than in early June. Rye regrowth on the no-till, mow-kill system was controlled by a grass herbicide, Poast®.

Soybean yields did not differ according to the rye management methods in 1988. In 1989 the best yields were produced by the no-till, mow-kill and where the soil was plowed after rye was harvested. The soil plowed after harvest is a promising method since it allows livestock farmers to obtain a harvest and the soil is covered up until late May.

The no-till, mow-kill left the greatest amount of residues, averaging 90% ground cover. The only other system which left greater than 30% ground cover was the disc only method.

The plowed soil produced a heavy weed flush. The no-till, mow-kill had few annual weeds since they were controlled by the herbicide which was applied to control the rye

regrowth. In 1988, weeds were a problem since the dry weather reduced the effectiveness of the herbicide.

Field scale trials:

When using rye as a forage, the timing of the rye harvest is important as rye yield increases rapidly after boot stage while forage quality declines. In addition, there is a trade-off between planting soybeans on time and the increase in rye yield.

On a farm which tested the rye plowed versus rye harvested as forage prior to soybeans, the rye forage yielded 3.1 T/ha. It was low in crude protein and low in digestibility, and was fed to beef cows. Soybeans, which had been planted June 6 (1990) produced low yields (avg. 1.8 T/ha). The farm experienced high weed pressure and the soybean yields were similar for both rye management methods.

The farmer identified the forage harvest component as an advantage to his system in providing an early forage source either as hay or early spring pasture. The farmer plans to use rye for grazing prior to soybean planting and has purchased a fencing system, hence reducing costs of harvesting. The analysis showed that the value of rye @ $35/T outweighed the costs of mowing (@ $20/T) and baling (@ $39.50/T).

SOYBEAN NO-TILL SYSTEMS WITH RYE

This set of experiments tested the no-till soybean system which included a fall rye cover crop into which the soybeans were seeded by various methods: rye was harvested and soybeans were no-tilled, soybeans were no-tilled and followed by rye mulched at two different timings (early and late), or rye was mulched and followed by soybeans no-till seeded, at two different timings (early and late).

Substantial amounts of rye were produced by heading, and 60% more dry matter was produced by anthesis. The protein content of the rye decreased from 12 to 9.8% between heading and anthesis.

All systems provided high ground cover (>90%). There was less rye regrowth where the rye was mown; the mulch suppressed weeds in addition to suppressing its own regrowth. The mown plots contained mostly perennial weeds and there were fewer weeds where the rye was mown after soybeans were planted than where the mowing was before planting. The soybean stand was sparse and there was lack of mulch where the rye was harvested; this led to significant weed growth.

The best soybean yields (3.04 t/ha) resulted from where soybeans were no-till planted into the standing rye which was then mowed early. The worst yields resulted from late mulching followed by no-till seeding of soybeans. Planting into standing rye enabled better seed placement than was possible when the rye was mowed before planting. Where rye was harvested the double crop total production was satisfactory: 3.45 t/ha rye, and 1.8 t/ha soybeans.

Field scale trials:

In a comparison of rye mowed versus herbicide killed, rye regrowth occurred in the mowed plots and there was a crabgrass infestation, requiring the use of a grass herbicide and cultivation of the plots. The mowed plots remained weedy. The systems produced similar soybean yields (avg. 2.1 T/ha). The cost of mowing was slightly lower than the cost of applying a low rate of Roundup® and input costs are unlikely to be a determining factor for a farmer selecting this system. The farmer suggested that the potential for yield reductions due to rye regrowth and the increased perennial weed pressure make the system too risky.

In a comparison of rye killed with herbicide versus conventional no-till soybeans without a rye cover crop, soybean yields were similar (avg. 3.3 T/ha). Rye resulted in superior weed control even with both treatments receiving a comprehensive herbicide program. The rye resulted in a 90% reduction in nightshade. This was of interest to the farmer since his soybeans are grown for human consumption and their marketability is affected by discoloration by nightshade. The rye seeding cost was estimated at $12.50/ha. The farmer was interested in long term benefits to soil fertility on the farm of the rye cover crop.

RYE VARIETIES IN NO-TILL SOYBEAN PRODUCTION

In a system in which soybeans are no-till seeded into a standing rye cover crop and followed by mowing, rye regrowth may be a problem. In this study rye varieties were compared for their differences in amount of regrowth in this system, their dry matter production, weed suppression, and soybean yields.

Aroostook and Ryeman varieties experienced some winter kill and produced thin stands and low ground cover. Kustro, Wheeler and 2 common rye seed lots produced approximately 40% ground cover. The largest above ground plant material was produced by Kustro and 3 common seed lots. Wheeler rye, which was bred for high forage production, produced less dry matter than earlier maturing varieties when it was harvested at heading.

Kustro had less regrowth than all other varieties. Wheeler exhibited considerable regrowth. Aroostook had high regrowth which was likely associated with the low amount of surface mulch it produced.

Soybean yields in this system were reduced by 40% on average on plots with winter rye, regardless of variety. Soybeans were short and chlorotic where rye was present. Yield reductions were believed to be due to potassium deficiency since the literature suggests that rye reduces extractable K when managed in a no-till system.

HIGH MOISTURE WINTER BARLEY-SOYBEAN RELAY CROPPING

In a relay cropped system, soybeans are no-till drilled in winter cereal in mid-May when cereal is 15 - 30 cm high. The cereal can be harvested as high moisture feed grain to reduce the cereal harvest date by 10 to 15 days. These trials compared relay systems of high moisture winter barley, of barley harvested at normal maturation, and the single crop systems of winter barley and of soybeans.

Winter barley yields were low because of poor to fair winter survival. High moisture yields were approximately 40% less than sole winter barley harvested as grain. The yield reduction relates in part to the immaturity of some grains at harvest which resulted in incomplete dry matter accumulation. Harvesting of mature barley in 1989 was difficult because the barley lodged and soybeans were etiolating and climbing into the canopy.

In both years of the trial no field harvest would have been obtained from the relay cropped soybeans as yields were low, beans were stunted, and the pods were low to the ground. Other problems with soybeans in the relay system were the lack of penetration of the no-till drill in hard, dry soil, and the lack of moisture after germination of such shallowly planted soybeans. Other problems with the system was the clipping of soybeans by the cutter bar during barley harvest, and damage to the beans by wheel traffic.

NO-TILL WINTER WHEAT AND RED CLOVER PLOWDOWN FOLLOWING SOYBEANS

The purpose of this trial was to compare establishment methods of winter wheat following soybeans. Winter wheat was broadcast into standing soybeans at leaf yellowing or was no-till planted with a conventional drill after soybean harvest. A conventional treatment in which the soil was plowed and winter wheat planted after soybean harvest was compared. Red clover was frost seeded in March.

Fall ground cover was high for both conservation systems and highest for the aerial seeding. Conventional seeding resulted in low ground cover (<30%) in autumn. The winter wheat established relatively well by aerial seeding at both sites, producing fewer number of plants at one site, and more plants, relative to other methods, at the other site. Winter wheat yields averaged the same for all methods. There were no differences in plowdown red clover yields or in weed biomass.

INTERSEEDED COVER CROP AND CATCH CROP SYSTEMS FOR WINTER WHEAT

Trials on two sites over two years evaluated the potential of red clover interseeded at different times and the potential of other seedings in winter wheat or as catch crops following winter wheat. Alfalfa, crimson clover and hairy vetch were used as interseedings in addition to red clover and were drilled into the wheat in May. Buckwheat and oilseed radish were used as catch crops and were seeded in August after cultivation of wheat stubble.

The interseedings did not affect winter wheat yields. Wheat yields were high and provided significant competition to the interseedings.

Hairy vetch consistently produced the most biomass. Red clover was more productive on the silt loam site in both years while alfalfa and crimson clover performed better on the sandy loam site in the drought year of 1988. Oilseed radish produced high levels of biomass on the sandy loam site but growth on the silt loam site was poor due to low soil nitrogen levels. Generally, the greater the biomass production of the interseeded crop, the greater the weed suppression. Cultivation after winter wheat harvest was very effective in reducing fall weed biomass and was further reduced by the catch crops on the silt loam site. Systems with interseedings or catch crops increased ground cover relative to no cover crops.

Field scale trials:

Comparing red clover frost seeded into winter wheat and hairy vetch drill seeded into winter wheat in mid-May showed that both legumes established well in the relatively wet year of 1990. When the legumes were plowed the following May and the area seeded to corn, the corn produced relatively high grain yields with no fertilizer (avg. 9.3 T/ha). Production costs of both systems were similar and corn yield differences negligible. Other considerations in selecting between the systems include the suitability of the timing of operations such as the addition of N fertilizer to the wheat, distribution of workload, and the farmer's equipment.

Two farms tested the use of oilseed radish after cereals, comparing the system to one without the radish. One farm incorporated liquid and the other solid swine manure after wheat harvest and prior to planting of oilseed radish.

The farm using solid manure produced less catch crop biomass than the other farm (2.5 vs. 3.7 T/ha). On the farm with liquid swine manure there were no differences in corn yields the following year; all plots received N fertilizer and the control received a sidedress application.

On the other farm, corn yields increased with the presence of the oilseed radish, most likely due to improved weed control on this treatment since the corn plant nutrition was apparently unaffected. There was some economic advantage to the use of oilseed radish at both farms; at one due to the elimination of the sidedress operation, and at the other due to slightly increased corn grain yields in the following year.

INTERSEEDED COVER CROP AND CATCH CROP SYSTEMS IN SPRING CEREALS

This trial was similar to that using winter wheat. Several cover crops were compared. In addition, blind harrowing was evaluated for weed control and as a method to enable later seeding of crimson clover and hairy vetch which if seeded too early can grow into the cereal canopy.

Yields of mixed grain were low because of drought in both years. There was no effect of the interseedings on yields. Hairy vetch tended to climb into the cereals at one site making direct combining nearly impossible.

Blind harrowing significantly increased weeds measured at grain harvest at the sandy loam site; this was likely due to lack of germination of weeds under dry soil conditions. At the clay loam site, interseeded alfalfa, crimson clover, and hairy vetch reduced weed biomass while red clover was less effective at competing with weeds.

At the sandy loam site alfalfa and crimson clover produced the greatest amount of forage by the fall, while on the clay loam site, hairy vetch produced the highest amounts. Highest biomass producing systems included liquid manure, oilseed radish and cultivation.

Ground covers were high on all plots as measured in the fall. Where no cover crop had been planted cereal regrowth accounted for the high ground cover. Manure applications increased the growth of oilseed radish and of cereal regrowth but suppressed the growth of red clover.

A companion study looked at mechanical weeding systems, harrowing, rotary hoeing, and finger weeding, and their compatibility with establishment of red clover, crimson clover, and hairy vetch. While these mechanical methods provided effective establishment methods for the interseedings, they were likely used too late for effective weed control.

NUTRIENT CONTRIBUTION FOLLOWING INTERSEEDINGS INTO CORN

Corn planted in the year following both the winter wheat and spring cereals interseedings trials on selected plots was to evaluate the contribution of the cover crops to corn fertility.

In one trial, hairy vetch provided the highest yields where no fertilizer was applied to the corn. All cover crops, including oilseed radish increased yields where corn was not supplemented with nitrogen fertilizer. The yield advantage of the cover crops in this case amounted to greater than 1 t/ha. There was no advantage at either site in this trial to corn grain yields at a fertilizer application of 40 kg N/ha. Overall, the cover crops provided a yield advantage to corn when the yields were averaged over fertilizer application levels of 0, 40, and 80 kg N/ha. The fertilizer nitrogen equivalent of the cover crops was considered to be 70 to 100 kg N/ha.

In another comparison, the contribution of the cover crops to corn yields differed; oilseed radish with or without manure, crimson clover, and manure applications without cover or catch crops, did not increase yields where no nitrogen fertilizer was applied. At another site there was no advantage of the cover crops relative to a control with no added N for corn yields. The five legume cover crops examined resulted in higher N and P contents of corn sampled at the five leaf stage, when compared with the three manured plots.

Field scale trials:

The nitrogen contribution of legume and oilseed radish cover crops was studied by tracking ammonium and nitrate levels in the soil in the spring. The data were to provide further information on cover cropping and the nitrogen soil test.

HAIRY VETCH AND RED CLOVER

On May 18, most N was in the nitrate form although much existed as ammonium (Figure E.2-1). On June 14, red clover showed higher N levels than the hairy vetch. There were no differences in corn ear leaf N levels according to the two cover crops or the fertilizer N levels applied (0, 40, 80 kg N/ha). Corn grain yields responded to fertilizer N additions. Both cover crops responded at the 40 kg/ha level of N addition.

OILSEED RADISH

Oilseed radish plots had more soil nitrates than plots without oil radish at one farm (Farm 1) but showed no differences at another farm (Farm 2) (Figure E.2-2). At each farm at soil N test time, nitrate levels were not significantly different for both oilseed and no oilseed radish. At this time levels averaged 20 ppm (Farm 2) and >21 ppm (Farm 1) at the two farms. On Farm 1 where soil nitrate levels exceeded 21 ppm there was no response to fertilizers and no response to the oilseed radish. At Farm 2 corn yields and ear leaf N responded to fertilizer applications regardless of the cover crop component.

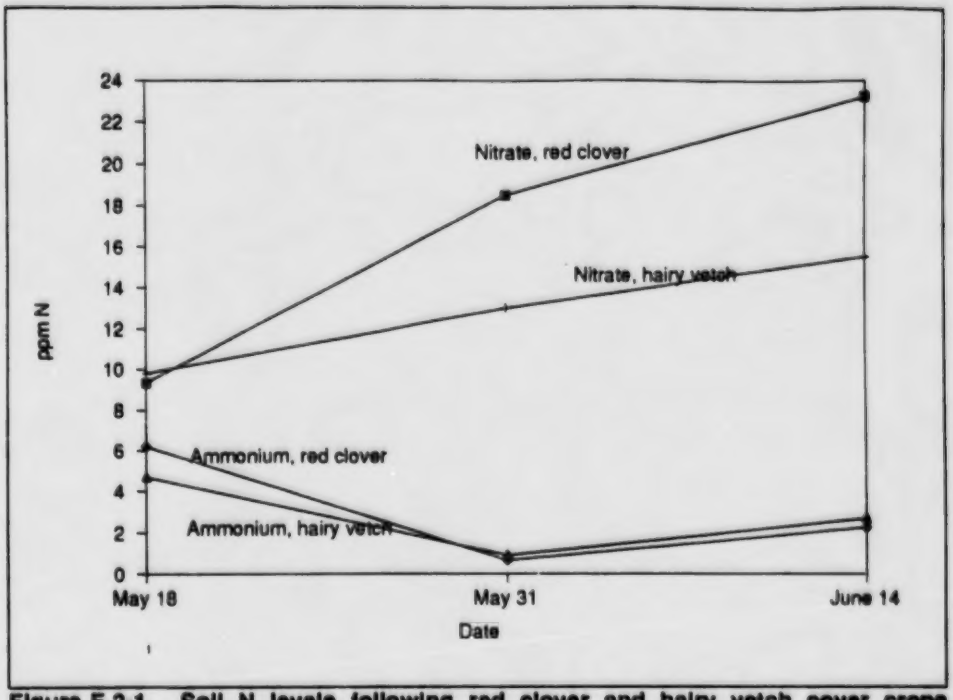


Figure E.2-1. Soil N levels following red clover and hairy vetch cover crops (adapted from SWEEP Report No. 57a)

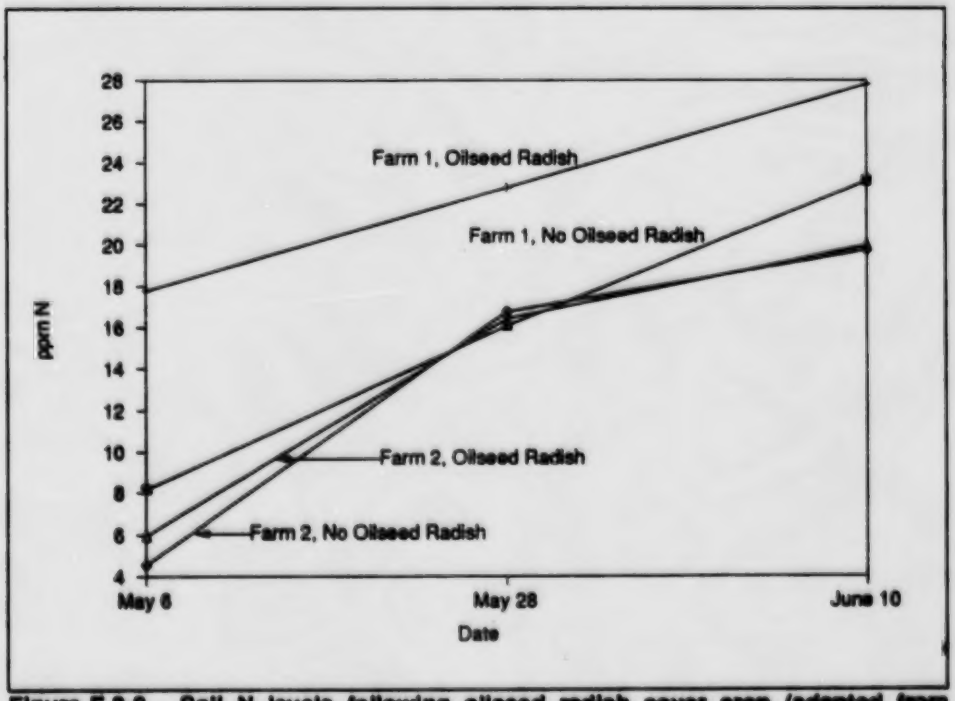


Figure E.2-2. Soil N levels following oilseed radish cover crop (adapted from SWEEP Report No. 57a)

The field testing concluded that the N soil test is valuable in predicting when N is in excess supply and thus aids in the management of N on the farm. It underlined the importance of sampling as late as possible to ensure that the N supply is not underestimated.

E.2.4 THE EFFECT OF ORGANIC MULCHES ON SOIL MOISTURE AND CROP GROWTH

(SWEEP REPORT NO. 29; PROGRESS BULLETIN ISSUE 4)

A system of fall rye as a cover crop followed by no-till soybeans was studied to determine the soil moisture and temperature relations of the system and the growth and development of soybeans. Rye was chemically killed then mowed at early and later spring kill dates while the non-mulch comparison consisted of chemical kill and plowing of the rye. Soybeans were no-till planted. The study was carried out on Fox sand (Delhi), Guelph loam (Woodstock), and Haldimand clay (Canfield). Phenological stages of soybeans were recorded in addition to weather parameters, and soil temperature and moisture measurements after soybean planting in the spring. The study was carried out during the 1988, 89 and 90 field seasons at Delhi, and for 1989 and 90 at the other two sites.

RYE GROWTH

The rye established well in 1988 and 1989 on the sand and loam sites. Growth rates at these sites were similar although dry matter accumulation differed because of less growth the previous fall on the loam site. The rapid growth rates of the rye in the spring resulted in considerably more rye present at the later of the two killing dates in both years.

Percent ground cover ranged from 32% (sand, early kill, 1989) to 91% (sand, late kill, 1990). The previous years' crop residues contributed up to 25 to 40% of the total residue on the soil surface. Accumulations of dry matter beyond 2000 kg/ha covered over 80% of the soil surface (Figure E.2-3). Beyond 2000 kg/ha, dry matter did not correspond with ground cover and did not significantly contribute to increased cover.

By mid to end -June most of the dry matter had disappeared (Figure E.2-4), indicating that water conservation by the mulch may not be expected beyond this time. An early spring fertilization was helpful to obtain adequate amounts of rye mulch at the sandy soil site.

SOYBEAN GROWTH

The date of occurrence of some stages of soybean development differed according to mulch levels. Differences were a maximum of 2 days at the sandy site (1990) and 3 days at the loam site (1989). The slowed development under mulch was due to the slow start of the soybeans which was attributed to problems in planting through the mulch. Major phenological stages, such as flowering, pod set, and harvest maturity, were generally not affected by the presence of rye. Slight yellowing of the soybean leaves was observed near the end of June where there was rye mulch at the sandy site in 1988 and 1990 and at the loam site in 1990.

Soybean yields were not affected by the rye at the sand and loam sites during the study years. The mulch did have some effect on the nodes per plant, the pods per plant and the seeds per pod. The later killed rye which had lower plant population at the sandy site in 1990 still produced soybean yields similar to the early killing and no mulch by producing more pods per plant, and more seeds per pod. At the clay site no mulch produced a higher soybean yield than the mulch because the mulch produced a lower stand and growth due mainly to planting problems and the occurrence of slugs in the mulch.

The tendency of larger nodule biomass and number on some sampling dates, and higher number of seeds/pod observed in some years where there was mulch indicates that less water stress may have been occurring under the mulch relative to where mulch was absent.

SOIL WATER

There was a drying effect of the growing rye at the sandy site during 1989, which was the drier of the two springs. The most drying was observed for the later killed rye. By soybean planting time, however, rainfalls had replenished the soil profiles so no differences existed between mulch treatments.

Soil surface drying rates were lower under mulch early in the soybean growing season. Cultivation of the loam soil (no mulch) produced a sharp decline in soil moisture early

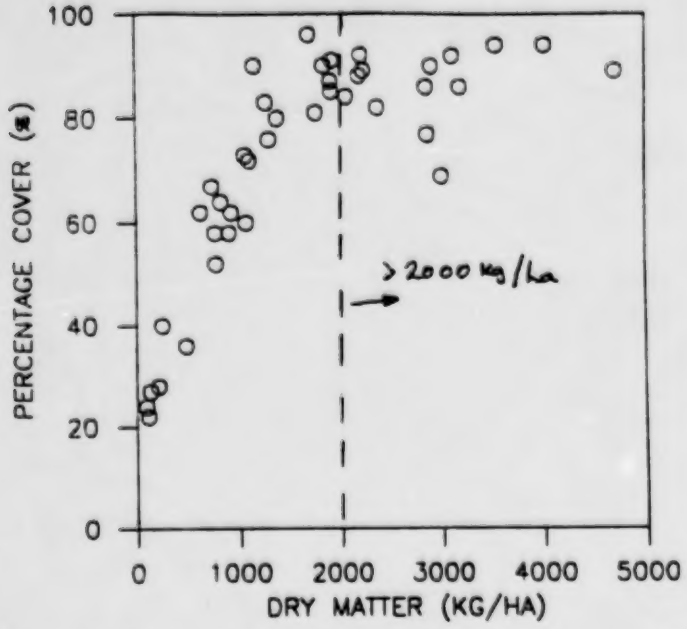


Figure E.2-3. Where rye mulch exceeded 2000 kg ha^{-1}, there was no increase in percentage ground cover by delaying the rye killing.
(copied from SWEEP Report No. 29, Figure 12)

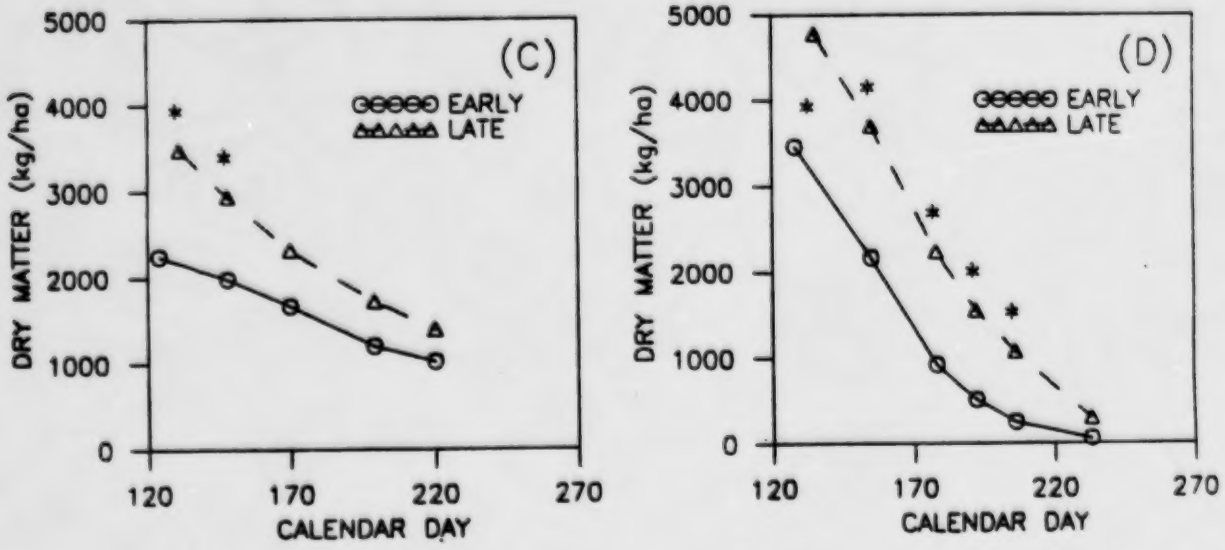


Figure E.2-4. Mulch decomposition rates were higher for higher initial amounts of residue.
(copied from SWEEP Report No. 29, Figure 1.3)

in the growing season. Later season differences in moisture were only observed at the sandy site in 1988.

Soil Temperature

At all three sites during the months studied, the tendency was for the soil temperature under the mulch to be in the cooler and warmer soil temperature classes less frequently.

Correspondingly, the mulch had a larger frequency of hours in the middle temperature range compared with no mulch. During the day maximum temperatures were lower and the minimum temperatures were higher. This had a large effect on some days but overall, the effect was not large (Figure E.2-5). The literature might suggest that reduced maximum temperatures under a no-till mulch benefit soybean growth and development. There is some speculation that lower variability in temperatures under the mulch would benefit microbial populations and activity as well as crop growth.

In general the rye-soybean system was considered satisfactory on sandy and loam soils. On clay soil the excess fall moisture and winter kill interfered with cover crop establishment. Planter problems and slug damage associated with the mulch decreased soybean yields.

Temperature and moisture differences had no effect on soybean yields. Some delay in emergence due to the residue was compensated for later in the season.

Computer Modelling

A soybean growth model and a model of mulch effects were developed and the effect of mulch on soil water and soybean growth was simulated. The findings were that the simulation of soybean growth in southwestern Ontario by the model, was satisfactory. The simulated soil water content under bare soil was close to measured values and the mulch effect on soil water was well described by a simple empirical equation.

The drying effect of rye was not considered in this simulation. It was not important in the field trials either, although it may be important in a dry spring.

The field and modelling experience have shown that large amounts of mulch are needed to positively influence yield through improving water relations. The feasibility of producing such large amounts of rye before soybean planting has not been thoroughly considered.

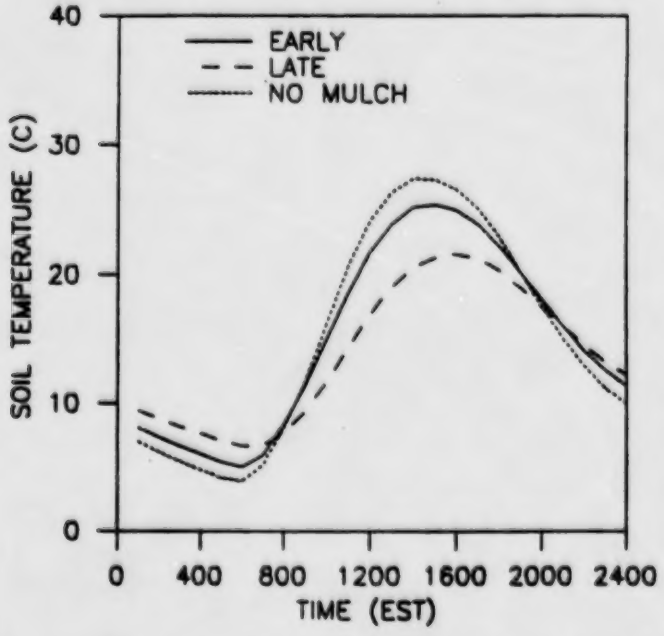


Figure E.2-5. Under the mulch, maximum temperatures were lower and minimum tempereatures were higher, relative to no-mulch.
(copied from SWEEP Report No. 29, Figure 12)

E.2.5 Efficiency of Residue Management for Providing Optimal Corn Growing Conditions in Non-Tilled Sandy Loam

(SWEEP Report No. 21; Progress Bulletin Issue 13)

The main effect of crop residues left on the soil surface in zero-tillage is to lower soil temperatures. Corn development is well understood and has been shown to be regulated by temperature in the absence of severe soil water stress. In the early part of the life cycle of corn, when the apical meristem is below ground, corn development is driven by soil temperature and the accumulation of degree-days at the level of the meristem. In spring, the presence of crop residues lowers soil temperature and corn development is typically slower than in a bare soil simply because the accumulation of soil degree-days is slower. However, the *number* of degree-days required for the corn plant should be the same as in a bare soil. If the number of degree-days required for leaf emergence were larger than in the bare control, then it is expected that something in addition to soil temperature is affecting corn development.

Research carried out during 1990 involved an examination of soil temperature effects on the growth and development of corn. Soil temperature effects were induced by different residue management regimes. The research attempted to answer several questions:

1. How do plant residues and their effect on soil temperatures affect corn development in a non-tilled soil?
2. Are observations of unevenness of emergence and plant establishment which sometimes occurs in no-till corn fields related to some spatially variable soil property?
3. Can residue effects on corn due to low temperature be distinguished from other residue effects?

Three separate experiments were set up to examine the above questions. Experiments 1 and 2 were on a Harrow sandy loam soil, in Essex County. Experiment 3 was at the Elora research station on a Guelph loam. Each of the experiments involved an hourly collection of soil temperatures at seed depth and detailed observations of corn vegetative growth which included emergence of 1st leaf, and leaves 4 through 16, tasselling, and silking.

Experiment 1

Experiment 1 compared two corn hybrids (P3790 and P3902) in several residue management systems:

- conventional (spring plowed)
- no-till (first year no-till following corn)
- trashwhipped (first year no-till with residues removed from the row into the interrow)
- bare (first year no-till with all residues removed).

In Experiment 1 corn plants developed at different rates during the vegetative period. Figure E.2-6 shows a set of soil temperatures for a typical 24 hour day in May, 1990. The pattern is similar to that of the sandy soil studied in SWEEP Report No. 29 and discussed in the preceding section (E.2.4). The no-till soil was the warmest in the early morning (3 to 7 a.m.) but soil temperatures were not as high during the day as they were in other management systems. Generally, corn in the bare soil reached growth stages first, followed by the conventional, the trashwhipper, and the no-till management systems. Corn required the same number of degree-days to reach particular stages in all management systems. Therefore, different rates of corn development were attributed entirely to differences in temperatures under the various residue management systems.

Early in the season, the trashwhipped, bare, and no-till soil had significantly higher interrow water contents than the conventionally tilled soil. This indicates that the higher water content among treatments may be due as much to the absence of tillage in the fall and spring as to the presence of residues on the soil surface.

Maximum differences between the no-till and other residue management systems were observed at the 11th leaf stage. At this stage corn development in the no-till system was 5.2 days behind corn development in the bare soil, 4.7 days behind the conventional tillage system, and 2.5 days behind the trashwhipped system. Thus, half the delay due to the presence of residues on the no-till plots (5 days) could be avoided by clearing the residues off the row (2.5 days delay).

There were also differences in grain yield per plant at the end of the season. In fact, for one hybrid, P3902, no-till, which developed most slowly, resulted in the greatest grain per plant, and the bare soil, which developed most rapidly, yielded the least grain per plant. In P3790 there

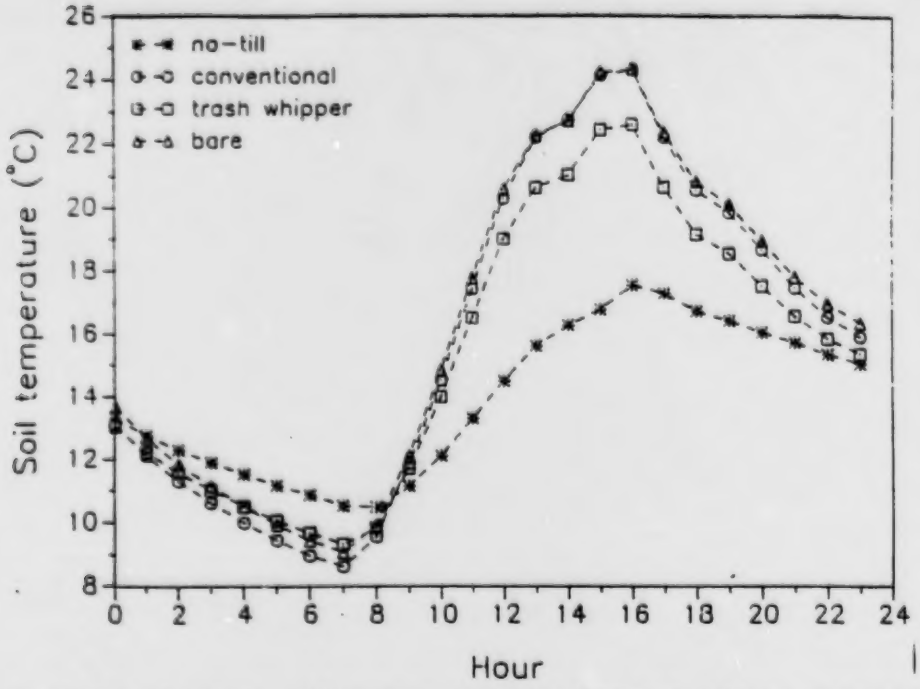


Figure E.2-6. Seed zone soil temperatures in May 1990 for 4 residue management methods. (copied from SWEEP Report No. 21, Figure 2).

were no significant effects of residue management on plant grain yields. P3902, an earlier maturing hybrid, had a higher average grain yield per plant than P3790. Final plant populations were similar for each hybrid and all residue management.

Experiment 2

Experiment 2 compared two corn hybrids (P3790 and P3902) in first year no-till and conventional management (spring plowing). Emergence counts, and soil measurements of bulk density, soil water, and seed depth were taken. The objective of the experiment was to quantify the variability of final plant establishment and emergence patterns, to identify spatial and random components of this variability, and to relate the variability with soil tillage factors. Experiment 2 examined the spatial variability of soil parameters and compared them with the emergence characteristics of two corn hybrids.

The largest variability in number of plants per length of row was observed on the first day of emergence. The variability of emergence observed on Day 1 was greatest in the no-till system and it was spatially dependent in the no-till but not in the conventional tillage system. Variability of seedling emergence on Day 1 was correlated to soil water contents. These results suggest that hybrids used in a no-till system should be screened for tolerance to no-till environmental conditions at planting; ie., low oxygen/high water tolerance and low temperature tolerance.

Final plant stands ranged between 80 and 90% for all tillage methods used. The variability of the final stand was similar for no-till and conventional systems.

Experiment 3

Experiment 3 compared corn development of leaves 4 through 8 under several types of residues in a no-till system, with and without trash whippers. These residues are: grain corn, spring canola, spring barley, spring barley + red clover killed early, and the same, killed late, soybean, soybean + fall rye killed early, and the same, killed late.

Corn grown in the no-till system in no residues as well as in residues of grain corn, spring barley, spring barley + red clover killed early and late, soybean, and soybean + fall rye killed early and late, required a similar number of degree-days for the development of corn leaves 4 - 8.

Corn plants growing in a no-till system with canola residue developed normally from emergence of leaves 4 to

6 but required 27% more degree-days than the bare control from leaf 6 to 8. This indicates that the corn development with spring canola was affected by another factor in addition to low soil temperatures due to the presence of residues. This factor could be disease, nutrient deficiency or allelopathy although there was no sign of disease or nutrient deficiency. This requirement for more degree-days was eliminated using trashwhippers. The effectiveness of residue removal with the trashwhippers suggests that if allelopathic chemicals are involved in the retardation of corn development in canola residues, these chemicals are likely to have low volatility and low solubility in the soil solution.

The observed development of corn grown in residues of soybean + fall rye killed late behaved inconsistently between replicated observations. This indicates that this residue may affect corn development other than by lowering soil temperature.

E.2.6 Response of Corn Hybrids to Type of Tillage

(SWEEP Reports No. 22 and 59; Progress Bulletin Issue 9)

Several studies examined the relationship of tillage systems to the growth and development of corn hybrids. Field research tested the response of corn hybrids to conventional and conservation tillage systems. Tests on corn hybrids were carried out to examine their cold tolerance during the critical stage of germination and early growth in an effort to develop a method for the selection of suitable corn hybrids capable of good performance under no-till conditions. After initial field and lab tests, larger scale studies continued in an effort to fortify the earlier findings. The results of all these related studies are presented here.

Field Studies

A study was conducted in 1988 to establish the relationship between corn hybrid performance and tillage method. A no-till system which had been established for seven years and a conventional tillage system were compared. Five hybrids from each of two commercial corn companies were studied for each tillage system.

The researchers noted that hybrids which were ranked as weak performers under no-till conditions suffered from delayed emergence and slower seedling growth. In addition, they observed marked reductions in plant population under no-till conditions in some replicates but not in others. Plant stands were much more uniform for all hybrids when the plots were plowed and a seed-bed was prepared with conventional secondary tillage. Grain yields were directly related to final plant populations.

Researchers interpreted these findings to mean that the variability of the plant stands in no-till reflected the reduced ability of some hybrids to perform under stress conditions occurring under no-till. The stresses are assumed to be cooler spring soil temperatures, higher soil density, or some micro-toxic condition attributable to crop residues on the soil surface.

Hybrids that performed well in the conventional tillage system were not necessarily the best performers in the no-till system. This result refutes an hypothesis that different hybrids will perform similarly in conventional and no-tillage systems. This was expected since hybrids have been developed almost exclusively under conventional farming practices.

Initial Laboratory Tests

Laboratory tests were designed to determine whether hybrid differences could be predicted. Corn breeders at the Agriculture Canada Plant Research Centre in Ottawa have studied cold tolerance of corn and have found no apparent relationship between germination and seedling growth at low temperatures and have also found that:

1. Good germination in near optimal conditions is no indicator of germination at other temperatures. Low temperatures are stresses and will tend to bring out the variability in genetic material, which would otherwise be hidden at more optimal temperatures.
2. Plants which germinate uniformly over a short time in cold temperatures are preferred over those which germinate erratically over a longer period.

3. Shoot (referred to as the coleoptile at this stage) and root emergence from the seed coat at low temperatures do not guarantee the success of a plant because growth often stops when the newly emerged plant axes are less than 1 cm long.

4. There was little or no correlation between germination and good early growth at low temperatures.

5. Cold tolerance during germination and early growth cannot be predicted from Ontario Corn Heat Unit (CHU) ratings for individual hybrids.

Further, since corn hybrids have not been selected for high cold tolerance in early stages of growth, there is a random distribution of tolerance found in the genetic material. Corn seed is comprised of three types of tissue, each with a different hereditary makeup: the embryo ('germ') has equal contributions from both parents; the seed coat is derived entirely from the female parent; and the endosperm inherits two thirds its genetic material from the female and one third from the male parent. In research cited in the report, breeders have concluded it was not possible to predict corn hybrid cold tolerance based on that of the inbred parent.

In 1990, the performance of corn hybrids used in the field tests in conditions of low temperature germination and low temperature growth was examined in order to link the response of hybrids in the lab to field observations.

During germination at 11°C, three growth parameters were measured: (i) time- to-root germination, (ii) time-to-shoot germination, and (iii) time-to-production of 1 cm coleoptile growth. The findings indicated that time-to-production of a 1 cm coleoptile was the best predictor of cold tolerance under no-till management practices. This parameter measured low temperature tolerance to both germination and early growth. Use of this predictor allowed easy identification of hybrids which would appear to be well-suited to no-till practice. In addition, time-to-root germination would further narrow the choices of hybrids which would be successful in no-till systems.

Low temperature (12°C) growth was observed for a period of 4 weeks. Information on growth at low temperature was shown to be useful but is not in itself a good predictor of field emergence.

This preliminary study suggested that recommendations for a hybrid screening process include determining for each hybrid:

- the number of seedlings showing root germination after 6 days, and
- the number of seedlings showing a 1 cm or longer shoot (coleoptile) after 22 days, when incubated at 11°C.

Further Field Testing and Relation with Laboratory Prediction Testing

In 1991 laboratory work on cold tolerance prediction continued in a attempt to provide a more rapid measure on more hybrids. The study involved two sets of readings per hybrid, thus permitting a larger number of measurements: (1) at 25°C, 10 days after imbibition - number of seeds germinated and number of seeds that produced a 1 cm long coleoptile, (2) at 11°C, @ 5, 6, 20, 22 days - number of seeds that produced a root (each of the 4 days) and the number that had grown a coleoptile 1 cm long (on days 20 and 22).

In the study of 122 corn hybrids in 1991 the development of the field predictor indicated that the best single predictor was coleoptile growth, that some hybrids have slow development of a primary root, and that there is a highly significant correlation between root and 1 cm coleoptile production under cold stress.

The study proposed that the best predictor, pending confirmation with field data from Ontario is:

$$CT = \frac{(1 \times Day_x) + (3 \times Day_{22})}{4}$$

Where Day_x is the % occurrence of root or coleoptile, respectively, 'x' days following imbibition. The predictor puts primary emphasis on coleoptile data yet incorporates some root germination weighting, in addition to providing a scale of 1 to 100.

Three levels of ratings for cold tolerance emergence of very good (1), good (2), and average (3), based on statistical measures of dispersion are separated at 68 (1-2) and 41 (2-3) on the scale.

No significant correlation was found between the predictor and germination at 25°C, indicating that the predictor is not biased towards low seed viability at 25°C. Of 122 hybrids tested, the majority germinated well under 25°C conditions, with an average germination of 92%.

Field studies carried out on 58 of the hybrids in 1991 were unable to distinguish the hybrids for cold tolerant emergence because the soil temperatures were warm during the critical period following planting.

E.2.7 Effects of Rye Mulches and Fertilizer Amendments on Nutrient and Weed Dynamics in No-Till Soybeans

(SWEEP Report No. 57b)

Two field studies examined the effects of rye mulch in no-till soybean systems. In particular, soybean and weed growth were studied to distinguish the physical, chemical, and nutrient components of a rye mulch in no-till soybeans. The study hypothesis was that the rye mulch was affecting soil nutrients by 1) its rapid spring growth depleting soil nitrates, and 2) the rye residue resulting in nutrient immobilization by the soil microbial biomass. Nutrient effects of the rye were considered to influence the amount and type of weed growth, with the rye resulting in fewer weeds and fewer of the nitrogen feeding weeds relative to where there was no rye.

Both field trials were located in Thamesville, Kent County.

Mulch Experiment

This trial attempted to distinguish the physical, chemical, and nutrient effects of rye by using: (i) rye mulch grown and left in place (physical, chemical, and nutrient), (ii) rye grown and removed (nutrient), (iii) rye moved into place (physical and chemical), (iv) poplar excelsior moved in place (physical), and a bare plot (none).

At four weeks after planting, the soybeans were the smallest under the rye mulch left in place. Similarly, at four weeks, the rye left in place resulted in the lowest soybean tissue N concentration which was exceeded under all other treatments except where the rye had been grown in place then removed. By eight weeks after planting there was no treatment effect on nitrogen content.

The various treatments had a large effect on weed biomass. The bare soil treatment had the most weed biomass and the rye mulch produced the least. The remainder of the treatments produced a similar amount of weeds which lay in between the two extremes. The dominant weed species were ragweed and lamb's quarters. The rye mulch reduced the biomass of these species and the numbers of nightshade and foxtail. Reductions in weed biomass were in the order of three to five times due to the rye mulch system. The physical effect of either rye or poplar excelsior mulch reduce weed biomass. The rye cover crop grown in place but removed reduced weed pressure through a nutrient effect. The rye mulch grown and left in place reduced weed biomass to the extent of approximately the combined effect of the physical and nutrient effects.

Soybean yields, which were in the range of approximately 1.8 to 2.8 T/ha, were apparently affected by the weed pressure, resulting in the greatest yields with the rye mulch and the lowest in the bare soil plot.

Fertility Experiment

This trial compared weed and soybean response to combinations of nitrogen and phosphorus fertilizers in bare- and rye mulch- systems.

Soybeans grown in the rye mulch were smaller and had a lower nitrogen content measured 4 weeks after planting. This finding is consistent with the results of the other trial in this study. The rye cover crop appeared to reduce the availability of N and P to soybeans since P fertilization alone had no measured effect on soybean yields, and, N fertilization alone increased tissue content but did not provide the growth response that was identified with both N and P fertilization. By 8 weeks after planting all soybeans had adequate N nutrition.

Fertilization with nitrogen increased the biomass of weeds measured on the plots. Addition of 75 kg N/ha quadrupled weed biomass in the rye mulch plots yet the weed biomass was still only one half that of the bare plot fertilized with 75 kg N/ha. This implies that the physical effect in addition to the nutrient effect is significant in terms of weed growth.

Nitrogen fertilization of the unweeded soybeans resulted in reduced soybean yields, due likely to competition from weeds. Soybean yields were highest on the rye plots which received no N fertilizer and lowest on N fertilized bare plots.

E.3 TILLAGE OPTIONS

E.3.1 EVALUATIONS OF THE EFFECTS OF MODIFICATIONS TO THE MOLDBOARD PLOW ON ITS RESIDUE MANAGEMENT POTENTIAL

(SWEEP Reports No. 13 and 31)

The effects of changes to the moldboard plow on residue cover were studied, on a plot scale (SWEEP Report No. 13) and a field scale (SWEEP Report No. 31). Preliminary recommendations on such alterations were made to aid farmers in choosing the best strategy for modifying the moldboard plow they already own to maximize its potential for leaving crop residue on the soil surface. This practice is a low cost "first step" towards conservation tillage.

Plot scale studies were conducted in 1988 at three farm sites, all on clay loam soils. One site was on a cereal stubble, while the other two sites were on corn stubble. A follow-up field scale study was conducted in 1989 and 1990 at four farm sites, in Kent, Perth and Middlesex counties. Soil texture at these sites ranged from loams to silty clays. In all cases, the previous crop was corn.

The 1988 studies looked at three modifications (cuts) to the shapes of three moldboard types (general purpose, high speed and European) mounted on three makes of plows (White®, John Deere® and Overum®). The 1989 field scale study looked at three cuts to the moldboard shape and one control (full moldboard treatment). In addition, a Norcan Minibottom® was tested at one site.

Soil surface residue cover was measured on four occasions: after harvest, after plowing, after spring run-off and after planting. Volumetric soil moisture content was measured at the time of plowing and the acceptability of the tillage operation (in terms of soil surface roughness) was rated.

The findings of both the plot scale and field scale studies may be summarized as follows:

1. In 1988, the plows that had three cuts normally left the highest percentage of surface residue, since they inverted the soil the least.
2. In 1988, none of the treatments achieved 20% residue cover after spring runoff.
3. No definite conclusions were reached concerning the effect of the moldboard modifications to the draft or pull of the plow. Draft differences were observed at each site, and for each plow type and treatment.
4. The soil surface roughness was rated unacceptable for most of the 3rd cut treatments, particularly at sites with a high clay content.
5. In 1989, residue cover at one site exceeded 20% after spring runoff. Two treatments (2nd and 3rd cut) at one other site exceeded 20% residue cover after spring runoff, while residue cover was less than 20% for all remaining sites and treatments. At the one site where it was tested, the Norcan Minnibottom® plow achieved higher post spring runoff residue levels than any of the modified moldboard treatments.
6. In the 1989-90 trials, no consistent significant differences were observed among treatments in soybean growth, development or yield.
7. Residue cover was affected by factors other than the modified moldboard treatment, such as depth of plowing and soil texture.

The researchers recommended additional studies on a variety of soil types and crop residues. Investigations should focus on the effects of different furrow widths, plowing depths and different moldboard modifications, particularly to North American type plows.

E.3.2 Monitoring and Evaluating the Effects of Spring and Fall Subsoiling

(SWEEP Report No.'s 16 and 24)

The effects of subsoiling on soil properties and subsequent crop yield were evaluated in two separate TED studies. In the first study, a B.C. Sub-mulcher® was pulled between corn rows at depths of 18 and 31 cm at 13 farms in Kent County in June of 1988. The goal of the 1988 study was to determine whether the practice of sub-mulch cultivation would benefit soil by overcoming the effects of compaction as shown by the porosity of soil, the extent and effectiveness of plant roots, greater plant growth or yield, and a reduction in the extent of ponding during rain storms.

The second study was conducted on 14 farm fields in Kent County in the September and October of 1989, after wheat harvest. This study evaluated the effects of subsoiling at a depth of 30 cm on soil properties and subsequent corn yield. Three implements were evaluated: a Tye Paratill®, Strohm Aerator® and a B.C. Sub-mulcher®. The ameliorative abilities of the subsoilers were evaluated in terms of soil conditions, yield response, implications to erosion and P runoff, and economic benefits.

Soils that had been identified as severely compacted showed structural improvements following the June 1988 sub-mulching operation. However, the improved aeration of the soils, particularly those subsoiled at a shallow (18 cm) depth, left the corn crop more vulnerable to drought conditions, as occurred in the summer of 1988. Thus, the shallow subsoiling treatment resulted in reduced corn yields in 1988. Deep subsoiling (31 cm) resulted in improved corn yields, particularly in severely compacted soils. One of the recommendations of this study was to pull a packer behind the subsoiler to close the openings left by the subsoiler shanks, thus reducing moisture loss through evaporation. Also, recommendations were made for further research into subsoiling timing and the effects of implement design.

In the second study, fall subsoiling resulted in improved soil structure, but yield increases in the year following subsoiling occurred on only two of the fourteen field sites. On these field sites the soil compaction rating was "moderate to severe." Thus, yield benefits from subsoiling are not likely to occur unless there is already a compaction problem. No benefits from subsoiling were observed when the same field strips that were subsoiled were deep plowed in the fall. This indicated that deep plowing may also be an effective remedy for soil compaction.

Of the three implements tested in the second study, the Paratill® provided the most effective and lasting benefits in terms of reduced soil compaction, but also required the greatest amount of draught.

The researchers acknowledged that favourable moisture conditions in 1990 resulted in good yields from both the subsoiled and control treatments. Also, since only two of the sites were rated as severely compacted, it was difficult to relate yield response to the subsoiling treatment. Soil erosion and phosphorus loss was not evaluated at any of the sites, and none of the farmers noticed reduced ponding on the subsoiled fields during storms.

It was recommended that farmers limit their use of the subsoiler to severely compacted sites. Recommended practices for alleviating or minimizing soil compaction included: reduction in axle loads, avoiding traffic on wet soils, limiting the number of passes over fields, particularly under moist conditions, and incorporating deep rooted crops into the normal crop rotation.

E.3.3 Machinery Modifications and Practical Tips

A TED contractor produced a booklet that documented the efforts of a group of innovative farmers to modify their conservation tillage implements for improved performance and/or residue management control. The booklet was printed and distributed by OMAF.

E.3.4 THE DEVELOPMENT AND TESTING OF A DRY FERTILIZER PLACEMENT MACHINE

(SWEEP REPORT NO. 25)

A prototype dry fertilizer zone-tillage machine was developed for applying dry form nitrogen fertilizer (urea and/or ammonium nitrate) in a conservation tillage system. Unless urea is incorporated promptly, much of its nitrogen will volatilize. Urea burns seeds if placed too close. The dry fertilizer machine applies the fertilizer in two bands, at a precise distance below and on either side of the seed. It is also suitable for side-dressing applications.

The zone-tiller is effective in no-till applications, leaving trash between the rows for protection against wind and water erosion. Only soil in the zone along the seed rows gets worked. The machine can be pulled in tandem with the planter, thus reducing the number of passes over the field, resulting in reduced compaction and fuel consumption.

The zone-tillage machine was developed to meet the needs of farmers who are interested in converting to a conservation tillage system, but are reluctant to use liquid 28% N or anhydrous ammonia fertilizers. Liquid 28% N and anhydrous ammonia fertilizers are more expensive than urea and require specialized storage tanks and injection pumping equipment. Conventional farmers who already use dry fertilizer may be more inclined to convert to a conservation tillage system if they could continue using the dry fertilizer, and obtain yields comparable to liquid 28% N fertilizer systems.

The performance of the zone-tillage machine, in terms of crop growth and yield, was compared with a standard liquid 28% N fertilizer applicator, that injects the fertilizer into the soil. The tests were conducted on a sandy loam soil at a farm in Brant County in 1989. A different field at the same Brant County farm was used in 1990, along with another farm site in Elgin County on a clay loam soil. Fertilizer was applied at two rates (50 lbs. and 150 lbs of N per acre) and at two timings (at planting and side-dressed at the 4-6 leaf stage). In the second year, two different fertilizer placement depths (5 and 15 cm) and three distances from the seed (10, 15 and 25 cm) were tested at the clay loam site. These additional tests were conducted to identify the minimum separation required for preventing seed burn and to determine whether different levels of volatilization (due to placement depth) would affect crop growth.

The results from the experiments are summarized as follows:

1. Yields from the dry form N treatments were greater for 9 of the 12 comparisons (rate/year/placement) of dry form N versus 28% liquid N.
2. At the sandy loam site in 1990, yields from the dry fertilizer N treatment were significantly greater than corresponding yields from the liquid 28% N treatments.
3. The treatments which were fertilized at planting outyielded treatments that were side-dressed at the 6 leaf stage for all but one of the rate/year/placement combinations.
4. The 150 kg N treatments outyielded the 50 kg N treatments for all but two of the 12 rate/year/placement combinations.
5. While there were no conclusive effects of varying widths and depths of the fertilizer placement when urea was applied at planting, the 25 cm width produced the highest yields.
6. When urea was applied at the 6 leaf stage, yields were significantly lower when the depth of placement was 15 cm versus the 5 cm placement depth.

The researchers attributed the encouraging performance of the dry fertilizer placement machine to a combination of split fertilizer placement (both sides of the row), the starter N in the ammonium nitrate form (20% of the total nitrogen in the dry fertilizer mix) and the coultering system. Since starter N was not used in the liquid 28% N treatments, the experiment could not conclude that urea fertilizer is better than 28% N fertilizer.

With the success of the dry fertilizer treatments, the researchers concluded that the fertilizer zone-tiller is a viable option for fertilizer placement in a conservation tillage system.

E.3.5 TYE-DRILL® MODIFICATIONS FOR SOWING SOYBEANS ON COMMERCIAL FARMS UNDER NO-TILL CONDITIONS

(SWEEP REPORT NO. 39)

In 1988, a study was initiated by a group of farmers in the Rondeau Bay area of Kent County. The goal of the study was to determine if more aggressive and better matched coulter/presswheel combinations would improve the performance of the Tye® drill for narrow row planting of soybeans in a no-till system. Experiments with the Tye drill in previous years had shown a tendency for poor seed establishment due to non-uniform seed depth, resulting in the exposure and desiccation of the seed.

In Year one of the study (1988), side by side comparisons of crop performance were made for fields planted with the Tye® drill and with conventional planting units. The Tye® drill was outfitted on one side with a bubble coulter and two V-presswheels with 8" rows, and on the other side with a fluted coulter and a single presswheel.

The results of the first year of research were inconclusive, due in part to the drought of 1988. While plant populations at two of the five sites were significantly higher on fields planted with the Tye® drill compared to the conventional planter, the differences in yields were not significant.

The study continued in 1989 using the same comparisons as in Year 1, with some additional treatments. The Tye® drill equipped with 1" fluted coulters across the front was outfitted on the left half portion of the drill rows with single presswheels while the other half had standard V-type (double) presswheels. On demand, a rake could be dropped behind the full width of the drill. It was hoped that one of these combinations would provide a more favourable seedbed environment, which would translate into greater emergence and yields.

The results of the 1989 field season were not encouraging for any of the Tye® drill treatments. At all of the sites, plants seeded with conventional planters experienced more rapid and vigorous emergence when compared to all other treatments. At all but one of the sites, the yield on the plot that was planted with the conventional planter was greater than any of the corresponding yields from the Tye® drill treatments.

The results of two years of experiments with the Tye® drill were inconclusive. Further minor adjustments to the coulters of the Tye® drill may improve the seed placement. There was some feeling amongst the farmers involved in the research, that the plot scale research may have introduced errors and biased the results in favour of the planters.

The farmers were disappointed with the results of the study. They had hoped to make the no-till drill perform well enough that they could eliminate the need for two separate planters; one to plant soybeans and one to plant small grains. This goal was not achieved with any of the configurations of the Tye® drill. In addition, it was observed that the Tye® drill was inconsistent in its performance across the field, tending to plant too deep at the crests of hills, causing a reduction in stand in these locations. The report did not reflect this problem because plots were positioned in the flat areas of the fields to avoid uneven planting depths.

E.3.6 COMPARISON OF PLANTERS AND FERTILIZER APPLICATION SYSTEMS FOR NO-TILL CORN

(SWEEP REPORT NO. 44)

Researchers from the University of Guelph conducted studies in cooperation with three innovative farmers to test and compare different seed and fertilizer placement systems on no-till corn planters. The research was initiated because it was perceived that conventional double disk openers on no-till corn planters were not always providing the seed with optimum growing conditions.

The effectiveness of the press wheels in closing the seed furrow appeared to be hindered by insufficient soil loosening around the seed. When the furrow is not closed, the exposed seeds are prone to desiccation. Most

modifications that have been made to no-till planters in response to this problem have involved mounting additional coulters or press wheels to the planting implement. The coulters till the soil in a strip into which seed and fertilizer are placed. While these modifications have helped to improve the seedbed, effective fertilizer placement is still a problem.

This study tested and compared three modifications to planters and fertilizer application systems.

1. In New Zealand, researchers have developed a planting system called the cross slot planter. It was tested in the U.S.A. with favourable results. The planter places seed and fertilizer with minimal soil disturbance above the seed. The fertilizer is placed slightly below and to one side of the seed.

   The parts for this planter were imported from New Zealand and installed on a four row planter by one of the co-operator farmers under a separate TED contract (SWEEP Report No. 42).

2. Recent studies at Guelph indicated that higher corn yields could be obtained if phosphorus absorption during early season growth could be increased above what is usually achieved with the conventional placement of 5 cm to the side and 5 cm below the seed. A John Deere 7000 planter was modified to use the strip band system, which allows fertilizer to be placed in two strips, 6 to 8 cm wide, on either side and slightly below the seed.

3. The coulter strip system is a variation of the strip band application which releases the fertilizer at the front edge of a fluted coulter. The fertilizer is mixed into a small volume of soil into which the seed is placed. The system was initially developed and tested in Michigan, where a 10 - 15 bu ac^{-1} increase in yield compared to conventional fertilizer application was recorded in Michigan in 1989.

The main objective of this study was to compare the cross-slot, strip band, and the coulter strip application systems with respect to uniformity of emergence, early growth, and P absorption. A second objective was to compare the cross-slot planter with a conventional system under varying soil moisture conditions.

Due to delays in receiving the cross slot units from New Zealand, the cross slot planter was not included in the 1990 field season trials. Only the strip band and coulter strip systems were compared. The cross slot planter was assembled early in 1991 and was included in the 1991 field season trials. A separate report (SWEEP Report No. 42) describes the cross-slot planter in detail. The 1990 experiments were carried out at two farm sites in Huron and Oxford Counties. The fields had a winter cover of red clover and no tillage was performed prior to seeding.

Two John Deere 7000 planters were modified and used in the experiment. Planter 1 was modified to allow fertilizer to be placed in three different positions: strip bands (10 cm wide strips on either side and 2 cm below the seed), conventional placement (5 cm to the side and 5 cm below the seed) and with the seed. Planter 2 was modified to allow fertilizer to be applied conventionally in 4 of the 8 rows. For the other 4 rows, fertilizer was applied over the edge of a fluted coulter mounted in front of and 5 cm to the side of each seed row.

Varying rates of fertilizer were tested at each site, including: no fertilizer, one half the rate recommended by the OMAF soil test system, the recommended rate, and 2x the recommended rate.

Oven dry weight and N,P,K concentrations were determined for shoot samples collected from each plot at the 3, 4 to 6 and 7 to 8 leaf stages. Emergence counts were made and silking measurements were taken on August 7 and 9 and leaf samples were collected for analysis at 50% silking. Final grain yield was determined at maturity by hand sampling a 5m section from each of the 2 centre rows. A subsample was taken to determine moisture content and shelling percentage.

The 1991 experiments were carried out at three sites, one in each of Kent, Huron and Oxford Counties. At one site, alternating strips were planted with each of the three planters. Within each strip, the fertilizer system was shut off for a distance of 50 feet at 2 times to allow separation of the effect of the planting system from the fertilizer application system. A similar set up was made on each farm except that at the second location, a standard planter was also compared to the other systems. A second experiment was conducted to compare the cross-slot planter with the conventional planter when the soil moisture content was both above and below optimum for a standard planter.

Measurements taken in 1991 were identical to those of the previous year with the addition of soil temperature and soil moisture measurements. Also, root samples were taken at the same stages as shoot samples from the plots receiving no fertilizer. They were assessed for mycorrhizal colonization.

The results from the 1990 field season showed no response in grain yield to fertilizer rate. In the absence of a response to rate, a response to placement would not be detectable. A high initial soil P content (18 mg/L) and a relatively late planting date may both have reduced the possibility of a response.

There was a response of early shoot growth to the first increment of fertilizer with both planters. Since the response was seen in both planters, this effect was also not due to fertilizer placement.

There were significantly higher yields with Planter 2 (6934 kg ha^{-1} vs. 6304 kg ha^{-1} with Planter 1). Since this yield difference was not due to the placement of the fertilizer, other explanations were sought. There was a significantly greater shoot P concentration at the 3 leaf stage with Planter 2 (4.33 mg g^{-1} vs. 3.6 mg g^{-1}) even when no fertilizer was applied. Subsequently, shoot dry mass at 4-6 and 7-8 leaf stages was also greater for Planter 2 as was the percentage of plants silked on August 7. These are typical responses of plants with a high early shoot P concentration.

The 1990 research results appeared to indicate that the increased shoot P at early growth stages was the cause of the increased yield with Planter 2. The reason for the greater shoot P concentration may be linked to the amount of soil disturbance - which is less with Planter 2 compared to Planter 1. The amount of soil disturbance affects the VA mycorrhizae which are formed between the plant roots and a range of fungal species. This symbiosis increases the ability of the plant to obtain immobile nutrients such as P from the soil.

In 1991, the strip band applications resulted in somewhat greater (not significant at p=0.05) yields at two sites, in comparison with the side band application system. It was concluded that the strip band was marginally superior to the side band system, but not sufficiently better to justify the planter modifications required.

The coulter-strip fertilizer application system showed no difference in early shoot growth, nutrient concentration or final grain yield compared to the side band system. However, poor planting conditions hindered the mixing of the fertilizer and soil, with the result that the fertilizer was mixed with only the upper 2-3 cm of soil.

Plots planted with the cross-slot planter system had yields comparable to the Guelph (split band) planter. The researchers acknowledged that, with more experience with the cross-slot planter, they may have been able to improve the planter set-up so that they could be certain that fertilizer was applied at the desired rate. Also, due to the hard ground conditions at planting time, additional weight may have been necessary to achieve proper penetration of the cross-slot units.

In addition to the comparisons of planters and fertilizer placement systems, the researchers were able to evaluate adequacy of the phosphorus fertilizer recommendations of the OMAF soil test system. Field experiments were conducted over a total of seven field experiments over three years (the last two years were supported by TED research funds), with fertilizer rates ranging from 1/2 to 4x the recommended rate. Not one of the sites showed any response to fertilizer P applications in excess of that recommended. Averaged over all of the sites, the recommended rate was the most profitable.

E.3.7 Evaluation of Row Crop Planter Modifications for Corn Production Within Conservation Tillage Systems

(SWEEP Report No. 41)

Tests were conducted with different coulter combinations and a range of attachments (trash whippers, rotary brushes, V sweeps) for moving crop residue from the row area during seeding of corn in a zero-tillage system. The goal of the research was to evaluate the different planter modifications in terms of their effect on seedbed conditions and corn growth and yield in order to assist producers in selecting planter attachments for conservation tillage systems. The residue clearing devices were tested on both corn and winter wheat (underseeded to red clover) residue. The experiments were conducted at a farm site in Wellington County in 1990. The 1991 experiments were conducted at the same farm in Wellington County and at two other farm sites in Oxford County.

Fourteen experimental treatments were examined over the two years of the study. The systems and modifications tested included a slot planting system, disk furrowers (one and two), wire brushes, spoked wheels and fluted coulters with and without the addition of brushes, spokes,

furrowers or a V sweep. A conventional (moldboard plowed) treatment was used as the control planting system.

Results of the study were influenced by the previous year's crop. Following grain corn, fluted coulters were effective in loosening soil and removing residue from the in-row area. Following winter wheat + red clover, additional residue clearing devices, such as disk furrowers or spoked wheels were required for clearing the in-row area. In-row residue removal led to slightly earlier corn emergence, but no yield advantage. Contrary to the results of previous studies by the researchers, which had shown suppressed yields, slot tillage in 1991 compared favourably to all of the other treatments, including the moldboard plow treatment.

The moldboard plow system resulted in consistently superior corn emergence, early growth and development, in comparison with the zero-tillage systems. However, corn yields were only significantly superior at one location. Within the zero-tillage systems, treatments which removed the in-row residue resulted in more rapid corn emergence, possibly due to more rapid soil warming.

The residue clearing devices, especially the disk furrowers, produced seedbeds with a higher bulk density, lower macroporosity and a higher penetrometer resistance. In winter wheat + red clover residue, these treatments resulted in lower corn yields. The aggressive action of the disk furrowers may have caused more smearing in the soil below the wheat + red clover residue, due to its greater moisture content.

The study did not find any of the planter modifications to be consistently superior. However, it did provide information may be useful for farmers who are looking to improve the performance of their planter in a conservation tillage system. The researchers recommended that similar evaluations be conducted on a variety of soil types and on other years, to test the effect of different climatic conditions on the performance of the residue clearing devices.

E.3.8 Management of Mulch Tillage Systems on Clay Soils

(SWEEP Report No. 40)

A wide range of mulch tillage systems were evaluated for their effects on soil properties and corn growth and yield. Experiments were conducted on two soils: a Huron loam near Lucan (Middlesex County) and a Brookston clay loam near Comber (Essex County). At each location, two experimental sites were established in the fall of 1990; one following a previous crop of grain corn and one following soybeans.

The aim of the study was to examine and provide recommendations on the effects of soil moisture content at the time of fall tillage and on the timing of spring secondary tillage within a mulch system. In addition, the following tillage equipment and systems were assessed for their impact on soil properties and corn growth:

1. No fall tillage; spring cultivate only
2. Moldboard tillage - wet
3. Moldboard tillage - dry
4. Offset disc - wet
5. Offset disc - dry
6. Chisel plow, sweep teeth - wet
7. Chisel plow, sweep teeth - dry
8. Chisel plow, twisted shovel, 12 cm - wet
9. Chisel plow, twisted shovel, 12 cm - dry
10. Chisel plow, twisted shovel, 18 cm - wet
11. Chisel plow, twisted shovel, 18 cm - dry
12. Chisel plow, twisted shovel, 18 cm - dry - early secondary tillage
13. Chisel plow, twisted shovel, 18 cm - dry - levelling harrow
14. Chisel plow, twisted shovel, 18 cm - dry - levelling harrow, early secondary tillage.

At each site, tillage was conducted at two different soil moisture levels, corresponding to "wet" and "dry" conditions.

Measurements of surface residue cover, soil surface roughness, soil moisture, aggregate size distribution and corn growth and yield. In June, following spring tillage and planting of corn, soil penetrometer resistance was measured for most treatments.

At the time of fall tillage, the range in gravimetric soil moisture between "wet" and "dry" conditions was 2-5%. Soil physical properties and crop response were not affected by soil moisture contents within this range. None of the mulch implements appeared to be less suited than the others to working in the wetter soil conditions.

After fall tillage the levelling harrow significantly reduced surface roughness without reducing residue cover. Chisel plowing at a depth of 18 cm, with no additional harrowing, resulted in the roughest surface texture. After corn, offset disking and chisel plowing with sweeps left more residue than chisel plowing. After beans, residue levels were about the same for all of the treatments tested.

In general, mulch tillage systems resulted in more favourable soil conditions and corn yield when the previous crop was soybeans, rather than corn. However, most of the mulch tillage systems reduced the residue cover to levels below that required for erosion protection. Thus, for erosion control following soybeans, it was recommended that there be no fall tillage and only minimal spring tillage.

Most of the mulch tillage systems provided adequate residue cover following corn, but soil physical conditions were inferior to the moldboard plowed treatments.

It appeared that harrowing after fall chisel plowing and performing early spring secondary tillage resulted in reduced soil drying rates. However, this finding may not have been evident under different climatic conditions than those of early 1991, i.e. for springs that did not have a prolonged drying period.

Grain corn yield in 1991 was higher at the Lucan site than at the Comber site. This was apparently precipitation linked, as Essex County experienced a mid-summer drought in 1991. Thus, it would appear that tillage systems play a minor role in final corn yield relative to precipitation.

At the Comber site, grain corn yields following corn were highest from the wet and dry tilled moldboard plow treatments. At the same site, no significant differences were detected when tillage followed soybeans. However, the lowest yields were recorded from the treatments that had been chisel plowed with sweeps. No grain corn yield differences were observed between any of the tillage methods at the Lucan site.

E.4 FERTILITY MANAGEMENT

E.4.1 The Effect of Split Applications of Nitrogen on Corn Yield under Ridge and No-Till Conditions

(SWEEP Report No. 28)

Trials were carried out in 1988 on two farms in Huron County to examine the relative merits of splitting the timing of the application of nitrogen fertilizer between planting and sidedress applications. Current findings have been that in southwestern Ontario sidedress applications of nitrogen have a yield advantage over preplant applications. Thus more nitrogen must be applied if the total season application is applied on or before the date of planting, relative to where a large portion of the nitrogen is applied later in the season, closer to the time of consumption by corn. The reason for the interest in splitting nitrogen particularly in conservation tillage systems is to attempt to get corn off to a good start and hence possibly overcome any phytotoxic effects of crop residues in these residue systems. The purpose of the study was to determine the probable optimum quantity of nitrogen to be applied in advance of the sidedress application.

The experiments involved applications of 0, 20 and 40% of the seasonal application of nitrogen at the time of planting, with the remainder of the nitrogen sidedressed. Trials were carried out in each of a no-till and ridge-till system.

There was no evidence from these trials to support the practice of splitting nitrogen applications or for the application of the entire season's nitrogen at sidedressing. However, in light of this study having been limited to one year's data collection, further testing may be warranted to more thoroughly examine the relationship of nitrogen timing and crop nutrition and grain yields.

E.4.2 The Use of Cover Crops for Nutrient Conservation

(SWEEP Report No. 43; Progress Bulletin Issue 8)

Both field and laboratory studies examined the role of cover crops in the cycling of nutrients under southwestern Ontario conditions. Cover crops provide soil cover and intercept raindrops, thereby reducing soil erosion. They also take up and release nutrients and their value to the nutrient supply to a following crop will depend on the rate of release relative to a succeeding crop's requirements. It is not understood to what extent the cover crops can retain nutrients and prevent their loss from the soil system, particularly during winter and early spring rains, in which the plant material may be leached of its nutrients.

Field Studies

In year 1, corn, barley and winter wheat were established and three levels of nitrogen fertilizer (0.5, 1, and 2 times recommended rate) were applied to establish variable residual N levels. Cover crops of oilseed radish, annual ryegrass, and red clover were seeded in or following the cereals. Annual ryegrass, red clover and winter rye were seeded in the corn crop. Weed control was either Tropotox or MCPA in the cereals, and Eradicane alone or with Bladex in corn. The field work was on one sandy loam (Ayr) and one loam soil (Woodstock Research Station) site.

The researchers were unable to establish cover crops in corn, and the study results mostly examined the responses in and following the cereal systems.

In the second year, the cover crops were sprayed with Roundup, chisel plowed, cultivated, and corn was planted. The corn received no nitrogen fertilizer except a small amount applied in the starter (14 kg N ha^{-1}).

Summary of Findings - Field Studies

In year 1, corn yields were unaffected by the level of N fertilizer applied. The response of the cover crop to the various levels of N varied with the site and in which crop it was growing or following. On both sites following winter wheat, the amount of oilseed radish was higher at higher N levels while the ryegrass and red clover did not vary according to the amount of N that was applied to the corn. On the other hand, at Woodstock, all cover crops

produced more biomass at the high N level following barley, while at Ayr, the cover crop growth was independent of the N rate, when following barley. The species of cover crop produced different degrees of dry matter at the different sites. At Ayr ryegrass had the least biomass, and red clover and oilseed radish, the higher, in general. At Woodstock the cover crop biomass levels were, in general, similar.

At Ayr, the amount of N contained in the cover crops increased from ryegrass to oilseed radish to red clover. This relationship was not evident at Woodstock. The amount of P was greatest in the oilseed radish.

The soil nitrate levels were lower following the cover crops in barley as measured in September but not in November. Then, in April and May, N was released from the oilseed radish, and by June, the greatest release of nitrogen into the soil was due to the red clover. There was a tendency for soil nitrate content following ryegrass to be lower than the no cover check, indicating that mineral N was immobilized. By June, the soil nitrate contents of the soil indicated that N release from the ryegrass and oilseed radish was not different from the soil without a cover crop.

The soil nitrate levels following cover crops in winter wheat were also lower in September and by November, nitrate in the soil was lowest with the ryegrass. Nitrate levels tended to be higher with the red clover and with no cover in September. Again, nitrate content in the soil was highest with oilseed radish in April and May. By June, a greater production of nitrate had occurred with red clover and some further production with oilseed radish. Soil nitrate following ryegrass was lower than with no cover, especially in June.

The ryegrass plots generally produced a rougher seedbed than other cover crops in the following year and at Woodstock following wheat, the ryegrass resulted in a 13% lower plant population for corn, and lower corn yields than other cover crops. Corn following red clover yielded significantly higher than following all other cover crops and no cover crop.

In terms of providing nitrogen to a corn crop, the difference in total weight and amount of N in corn after cover crops versus no cover crop is shown in Figures E.4-1 and E.4-2. Ryegrass resulted in an overall decrease in available N compared with the no cover crop treatment. Some residual N was available from the oilseed radish but the greatest amount was provided by red clover. Generally, yields of corn (weight) were lower following ryegrass and higher following oilseed radish or red clover. Grain yields were greatest following red clover and least following ryegrass.

LABORATORY STUDIES

The laboratory rainfall simulator was used to leach nutrients from the cover crop residues. The experiments used 2 loading rates of the cover crop, 2 of the field N rates, 2 different rainfall intensities, freeze/dry cycling, and 2 successive leachings.

The lack of any changes in the concentrations of N and P in the runoff during the second leaching indicates that there is a release of nutrient to the leaching solution over an extended period of leaching. Leachate from oilseed radish had considerably greater nitrate concentrations than

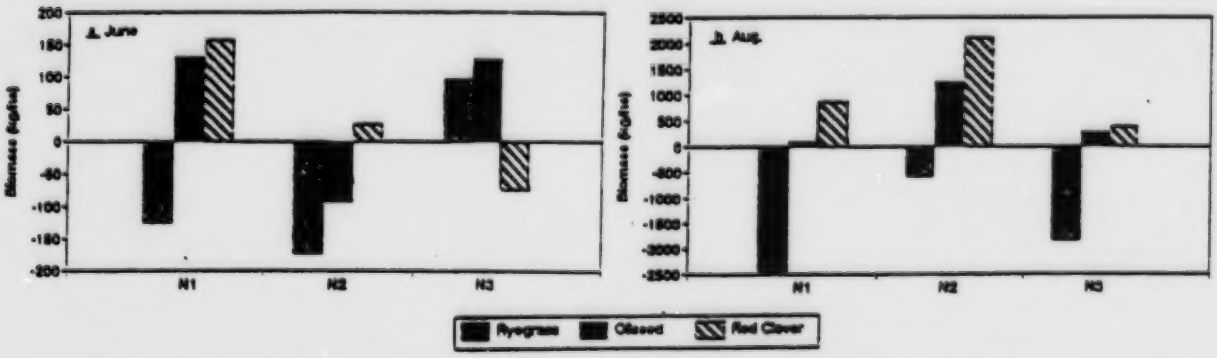


Figure E.4-1. Change in dry biomass of corn following different cover crops relative to no cover crop (N1, N2, N3 are different nitrogen levels). (copied from SWEEP Report No. 43, Figure 3.30)

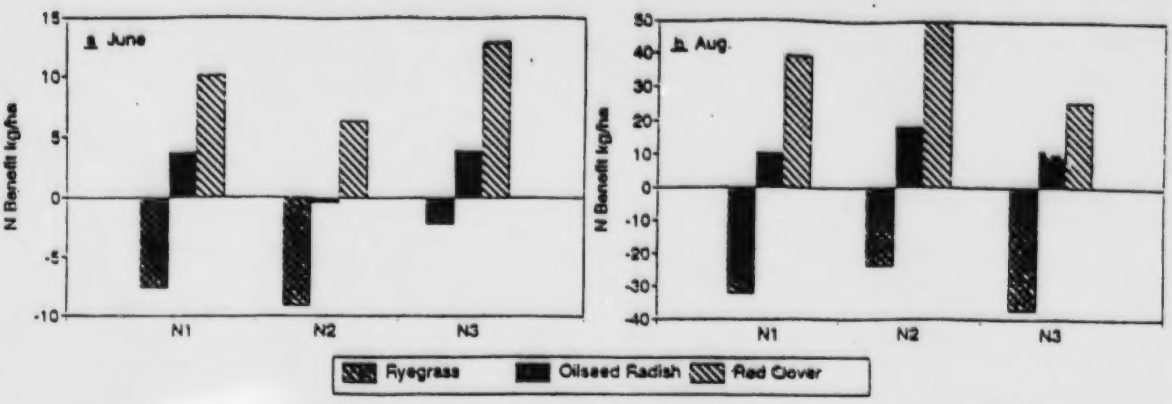


Figure E.4-2. Change in biomass N content of corn following different cover crops relative to no cover crop. (copied from SWEEP Report No. 43, Figure 3.30)

either red clover or ryegrass. P concentrations in the leachate were consistently higher for the high N rate on the main crop; this was probably a reflection of the higher P concentration in the cover crop with the higher amount of N applied in the main crop.

A lower proportion of N than P was removed from the cover crops by leaching. Including both leachings 5 to 10% of the N was removed compared to 20 to 33% of the P. A greater proportion of both N and P was removed from the oilseed radish than from the ryegrass. The lowest proportion was removed from red clover. Oilseed radish had a higher plant P concentration than other cover crops.

The total N and P concentrations were not greater than the inorganic concentrations (above) indicating that very little organic N and P was being leached. A total of 33, 72, and 18 kg/ha dissolved organic C/ha would be leached by 4000 kg/ha crop of ryegrass, oilseed radish, and red clover, respectively. While these values may not appear large, they may contribute to the substrate for denitrifying organisms.

The authors compared the concentrations of nutrients in the leachate with a study by Spires and Miller (1978) that examined nutrients in runoff from manured and non-manured fields. Ammonium levels in leachate from cover crops (1 to 3 mg/L) were approximately the same as from manured fields (2.8 mg/L; unmanured = 0.26). Nitrate from manured and non-manured fields averaged 7 mg/L and were similar to levels from cover crops @ 4 to 11 mg/L. Dissolved P was 0.16 mg/L (non-manured) and 0.70 mg/L (manured) in the Spires and Miller study while in this study levels were 1 to 3 mg/L from red clover, 4 to 11 mg/L for ryegrass, and 7 to 16 mg/L for oilseed radish. However, the cover crops will reduce erosion and therefore reduce the total P in runoff. This fact may be traded off by the fact that dissolved inorganic P is more bioavailable than sediment P.

E.4.3 Loss of Nitrogen by Microbial Denitrification, Nitrification, Surface and Tile Runoff: Relation to Tillage Methods

(SWEEP Report No. 51; Progress Bulletin Issue 12)

Nitrogen in soils occurs in soluble, insoluble or gaseous forms. The transformation from one form to another is due to microbiological or chemical activity. Transformation processes are influenced by a combination of factors such as oxygen, carbon, nitrogen, pH, temperature, moisture, and soil type. Some of these factors are influenced by soil management. In this complex system, nitrogen transformations and losses of nitrogen will vary widely over a field at any given time.

The objectives of the study are to determine the influence of several tillage methods on nitrogen transformations, and the effects of these methods on nitrogen losses and groundwater contamination.

Field Studies

Corn production systems have been found to contaminate tile drainage waters with nitrate. This field study attempted to establish the role of conservation tillage in corn systems in affecting the volume, concentration, and total amount of nitrates lost from tile and surface water flow in conservation relative to conventional tillage.

The field experiment was located near Woodslee in Essex County, on a Brookston clay loam. Experimental plots were established to collect surface and tile water samples. Each plot was centred above a tile drain which empties into an enclosed pit from which water samples can be collected.

This experiment compared continuously cultivated corn in conventional (moldboard plowed), ridge-tillage, and zero-tillage systems, and an uncultivated kentucky bluegrass stand.

Over 3 years (1989-91), tile effluent and surface runoff water was analyzed for ammonium, nitrate and nitrite content. Soil inorganic N levels and microbial biomass C were measured periodically from soil samples taken in the field.

The total volume of water draining through the tiles was greatest under conventionally tilled plots, and lowest under the bluegrass sod in 1989 and 1990. No differences between the two conservation tillage systems were evident. The greatest volume of flow occurred in Jan to Mar, 1991.

In all of the corn plots, regardless of tillage, the nitrate concentration of the tile waters exceeded 10 mg N/L (drinking water quality) in 79% of all the runoff events measured. The bluegrass sod resulted in <3 mg NO_3^--N/L in 88% of the runoff events in 1989 and 1990. Ammonium leaching in tile water was low, amounting to less than 0.25 kg N/ha from all systems. In 1991 the concentration of nitrate in the tile water was greater than in the previous two years due to the poor corn growth and N uptake resulting from the drought.

The total amount of nitrate lost in each event varied due to the combined effect of the concentration of nitrate and the volume of flow. The cumulative losses (Figure E.4-3) show that the conventional tillage had the greatest loss and the bluegrass the least. The average nitrate losses from the corn plots in 1989 and 1990 amounted to between 9 and 13% of the N fertilizer which was added.

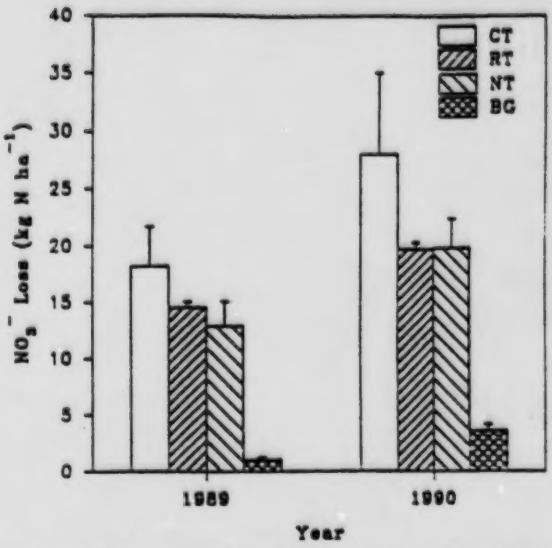


Figure E.4-3. Cumulative NO_3^- loss in tile runoff for conventional Tillage (CT), ridge tillage (RT), no-till (NT), and Kentucky bluegrass (BG) treatments.

(copied from SWEEP Report No. 51, Figure 1.7)

The ridge tillage system resulted in the greatest volume of surface runoff in all three years (1989-91), and the bluegrass sod caused the least runoff. The volume of water that drained through the tiles in the corn tillage system always exceeded the volume of the surface runoff, typically by a factor of 2 to 4.

The amount of ammonium lost in surface flow was low in all years (<0.2 kg N/ha). The average nitrate concentration in the surface water was greater for corn tillage systems than for bluegrass and differences between the corn systems were small. Nitrate losses through surface water were less than through the tile water in 1989 and 1990; both the volume of water and the nitrate concentrations were lower.

Conventionally tilled corn had the lowest grain yields in 1989 and 1990 with the conservation tillage yields showing opposite results in the two years relative to one another. The nitrogen uptake by the corn paralleled the yield results. Uptake ranged from 35-40% of the N applied in 1989, 41-50% of applied N in 1990 and 7-14% of applied N in 1990.

The Brookston soil exhibited shrink/swell characteristics. Cracks formed in the conventional system were greater than in the conservation systems which resulted in more water loss through preferential flow and through the tile system than through the surface flow. It is evident that management practices such as cover crops, intercrops, or

concentration of nitrate from tile waters in corn production systems.

LABORATORY STUDIES

Background and Potential Denitrification Rates

Denitrification is a process of conversion of nitrate (NO_3^-) to nitric (NO) and nitrous (N_2O) oxide and dinitrogen gas (N_2). It is facilitated by microorganisms in the soil that function under conditions of limited oxygen supply, and rely on carbon sources (such as crop residues) for their energy source. Minimum and no-till are expected to influence soil physical and biological processes, including those related to N-utilization, conversion, and transport. Background (existing conditions) and potential (under conditions where nitrate is not limiting) denitrification rates were measured over depths up to 0.9 m to identify the effects that tillage methods may have on the loss of nitrogen from the systems through denitrification.

The measurements were made on soil cores taken from the field in October 1989 and July 1990.

Background rates of denitrification decreased with depth and did not differ between tillage systems or sampling dates. Variability within and among sampling sites was high.

Comparing the potential denitrification rates with the background rates revealed that unamended soil of the bluegrass and ridge tillage treatments are more nitrate limited than the conventional and no-tillage plots. That is, on addition of nitrate to the bluegrass and ridge tillage treatments, nitrous oxide production was much greater while background rates were relatively low.

Most of the added nitrate was not denitrified after 3 days although microbial biomass levels were similar amongst treatments. This indicates that carbon was limiting. The low denitrification potential and low CO_2 production at depth below 5 cm suggests relatively low denitrifier populations at lower depths under all tillage systems. In these plots, denitrification would not be expected to significantly ameliorate nitrate loss by leaching.

Nitric and Nitrous Oxide Production: Water and Oxygen Effects

The effect of water in aerobic and partially aerobic soils is to restrict oxygen levels by reducing the air-water interfacial area within air-filled pores. Oxygen diffusion rates are slower in water than in the gas phase hence the oxygen concentration at the microbial cell is regulated by water content. Water also affects the movement of evolved denitrification gases out from the microbial cell.

This experiment studied the physical effects of NO and N_2O production under conditions favouring denitrification. Water contents and oxygen concentrations were varied under the experimental design to examine the relative production of the gaseous nitrogen products.

Oxygen inhibited NO production at low soil water contents but was less effective at higher soil water contents. Oxygen was more effective in depressing NO production in the Fox sandy loam than in the Brookston clay loam. Greater levels of NO evolved in drier soils and relatively greater levels of N_2O evolved in wetter soils.

E.4.4 MANURE MANAGEMENT IN CONSERVATION FARMING

(SWEEP REPORT NO. 58; PROGRESS BULLETIN ISSUE 10)

This study examined the use of manure in conservation tillage systems over three years in field trials. Four separate experiments were carried out. The research evaluated the agronomic implications of systems using combinations of reduced and zero tillage, cover crops, and manure forms, rates, and timing of application. The systems under investigation were designed to minimize environmental problems associated with manure on the basis that:

1. manure application to a rapidly growing crop allows its nutrients to be taken up and provides surface cover for soil erosion control;
2. manure incorporation using minimum tillage minimizes loss of volatile nitrogen, and allows crop residues to remain on the soil surface for erosion control;
3. planting a cover crop after manure incorporation provides a soil cover and may uptake nutrients that might otherwise be leached following manure application.

In these experiments the evaluation of the environmental component of the system was measured by rainfall simulation on some plots. The study relied on the premise of soil cover, minimum tillage, and timing of manure application in their being techniques that minimize soil loss, improve surface retention of water and possibly decrease the extent of nutrient leaching.

Manure Application in a Winter Wheat-Corn Sequence

Plots received liquid swine manure in the summer following winter wheat harvest or the following spring. All plots were cultivated or disced in the summer after wheat harvest, hence the summer manure application was incorporated. Following the summer manure, some plots were planted with oilseed radish. Fall tillage was one of: fall moldboard, fall chisel, spring airway, or not tilled. Plots which were plowed in the fall were cultivated the following spring. Corn was planted and all treatments were subjected to two levels of nitrogen fertilization (0 and 50 kg N/ha). The experiment was carried out over two seasons (3 years) at each of two sites (silt loam and sandy loam).

At both sites the highest fall ground covers were obtained with the systems that had oilseed radish and received no fall tillage. These plots had ground covers approaching 100%. No fall tillage regardless of the oilseed radish provided high ground cover (>90% on the silt loam and around 40-60% on the sandy loam). Chisel plowing resulted in high ground covers on the silt loam (>50%) but not on the sandy loam (avg. 20%) but were increased to 77% and 42% as a result of having grown the oilseed radish in the summer on the silt loam and sandy loam, respectively. Spring secondary tillage of the chisel plowed soil reduced the residue levels on the chisel plow plots. The aerway® and no-tillage systems generally maintained a minimum 30% residue cover by the time of corn planting.

Rainfall simulation was used on the sandy loam site to evaluate the soil conservation associated with selected treatments. Zero fall tillage reduced the amount of sediment loss by 72% relative to conventional (moldboard plow) while reduced tillage did not significantly reduce the amount of sediment loss measured in the fall. The amount of soil loss related to the amount of runoff since the sediment concentration in the runoff was similar. In the spring, the aerway®, zero-till and reduced tillage generated considerably less soil from rainfall simulation plots than the conventional system. Sediment losses were one and two orders of magnitude greater in the spring than in the fall.

The production of the oilseed radish was in the 2 to 3 T/ha range measured in the fall, and contained approximately 100 kg N/ha. Oilseed radish was effective in reducing soil nitrates relative to the summer manured treatment which had no catch crop as measured in the fall. In fact, the oilseed radish plots had nitrate levels as low as the plots which had not received the manure. The extent to which nitrogen was lost via leaching after the manure application was not measured. Since it its possible that nitrogen was lost before the oilseed radish was established, it was suggested that the oilseed radish be established and followed by an August or September application of manure. The drawbacks in this method might be the lack of incorporation opportunity and the loss via volatilization of the nitrogen. However, cooler temperatures and lower ground level windspeeds afforded by the growing crop may minimize this loss.

Spring manure application resulted in higher soil P levels at two of four sites. On the silt loam soil, corn tended to haver higher N and P contents at the five leaf stage where manure was applied in the spring. Oilseed radish seeded in the fall of 1989 reduced the P uptake in corn on the silt loam site in 1990. Oilseed radish tended to result in higher levels of soil nitrates in the spring, and fall tillage tended to increase the effect.

Summer application of manure generally resulted in lower corn ear leaf N than the spring application and on three of four sites, ear leaf N contents were high without the addition of fertilizer N. In 1991 oilseed radish increased ear leaf N in corn where manure had been summer applied.

Corn ear leaf K tended to be higher with increased tillage intensity. At all four of the study sites the highest ear leaf K level was associated with oilseed radish which had been fall moldboard plowed. At three study sites, the lowest ear leaf K was found where corn was no-till planted into oilseed radish residue.

Corn grain yield differences among treatments were evident where no additional fertilizer was applied. The higher corn grain yields were associated with the treatments which had higher ear leaf N contents. In 1991, the spring application of manure increased yields above the summer application. Increased tillage intensity tended to increase corn grain yield at the silt loam site, while on the sandy loam site there were few yield differences due to tillage.

The author suggests that it may be advantageous to split the high liquid manure application into two applications: one in summer after winter wheat in conjunction with an oilseed radish planting and one the following spring pre- or post- emergent corn.

MANURE APPLICATIONS IN RYE - NO-TILL SOYBEAN PRODUCTION

Manure management was evaluated in a system in which soybeans are directly drilled into standing rye at the time of anthesis in late May and the rye is mowed to form a mulch. This system provides soil conservation by way of fall cover of growing rye and into the spring, as well as a spring-summer mulch cover. However soybeans have been shown to produce less yield in the system with rye relative to a no-till system without rye. In this experiment, two rye seeding dates (late Aug, late Sept.) and with or without manure (prior to rye seeding and incorporated by discing) were compared with notill soybean systems with and without manure.

In both years the best fall ground cover was obtained where manure was applied to an early rye seeding (91%). The manure contained straw which increased the ground cover despite the fact it was incorporated by discing. Rye seeded late had a low ground cover (13%), which was surpassed by even manure alone (35%). By early May the rye treatments had high ground cover except for the late planted rye in one year which had slow growth in the spring.

Rainfall simulation indicated there was a 90% reduction in soil loss and a 60% reduction in runoff where rye was present as a surface mulch versus bare soil.

The highest amount of rye biomass was obtained when the rye was seeded early and manure was used as a nutrient source (>5 Mg/ha). However, time of planting had a greater effect on rye biomass production and composition than did application of manure.

The rye cover had no significant effects on P and K availability in the soil when measured in midsummer. Manure significantly increased soil K in both years and P in 1990. In 1991 early season soil nitrate levels were significantly reduced under the rye cover crop, particularly at the 0-20 cm depth where levels were very low (approx. 2 ppm N).

Soybean plant weights (30 DAP) were reduced where rye was present in 1991. In addition, plant N was reduced and % P in top trifoliate leaf at flowering were lower with the rye. Rye reduced soybean yield in 1990 and the late planted rye had poorer soybean yields than the earlier planted rye plots. Rye regrowth appeared greater in the late planted rye plots. In 1991 soybean plant stand was reduced by the use of manure and rye. The soybean yields were correlated with N content at 30 days after planting.

Early seeded rye was more effective than the late seeded rye in reducing the number and biomass of annual weeds and total weeds (annual + perennial). Manure apparently stimulated weed growth and the greatest weed biomass was evident in the manure + late seeded rye plot.

MANURE APPLICATIONS TO WINTER WHEAT

This experiment studied the use of manure in winter wheat systems. Several cropping-manure management issues were addressed by taking a conservation tillage approach.

Winter wheat was seeded by two no-till methods: aerial seeding into soybeans at leaf yellowing and no-till drilling after soybean harvest in the fall. A control plot was also established by using the conventional method of drilling after one cultivation following soybean harvest.

Manure was applied in late April when the winter wheat was growing. Manure was applied to the surface of the soil and the winter wheat in conjunction with soybean residues served as a ground cover for receiving manure. Red clover was established in the winter wheat to keep the soil covered after the winter wheat harvest, for erosion control.

Various nitrogen fertilizer and manure rates and forms (liquid swine and compost) were evaluated in this experiment to determine no-till winter wheat nitrogen requirements following soybeans as well as the agronomic potential and efficiency of manure applied in conservation tillage systems.

When no-till or aerial seeded techniques were used to establish winter wheat, a high ground cover (>70%) was maintained throughout fall and spring. Conventional tillage methods resulted in 20-30% fall ground cover. At the time of manure application in late April/early May, all the winter wheat systems had high ground cover (52-92%).

Winter wheat establishment method had no effect on the yield when averaged over the fertility treatments.

Averaged over the two years of the study, the low (40,000 l/ha) and high (80,000 l/ha) values of liquid manure provided plant nutrient analysis similar to the low (50 kg/ha) and high (100 kg/ha) rates of fertilizer, respectively. The two different rates of compost had no significant effect on the flag leaf N or the grain yield in 1989 relative to the control.

In both years, the winter wheat tillage system did not affect red clover or weed growth. The fertility treatments affected these parameters, however. In both years of the study, the treatments which resulted in the highest flag leaf N (winter wheat), produced the lowest amount of red clover, measured in the fall. Excessive application of either fertilizer or manure appeared to have greatly suppressed red clover growth and enhanced fall weed

growth. Lower rates of fertilizer and manure tended to favour red clover growth over the higher rates.

In 1990, the immature compost, which had significantly increased wheat yield, caused no reduction in clover development or stimulation of fall weed growth compared with the control plot (which had no fertilizer).

The combination of no-till or aerial seeded wheat with manure may be a promising approach to a wheat production system.

Manure Applications to Forages

This experiment was established to determine the effect of low rates of summer applied solid manure and compost on forage yield and composition. Concerns with manure applications to forage stands include smothering of alfalfa and the presence of manure in hay at harvest. This study made applications of solid beef manure, mature beef compost, fertilizer, or no amendments to an established alfalfa-timothy stand after first cut. The study based its evaluation of the system on forage composition (grass/legume), nutrition, and yield.

In the first year (1989) fertility treatments had no effect on forage yield or the forage composition. This site had low soil P and K test levels.

In 1990 by the time of the first cut of hay (ie., prior to year 2 manure application), forage yield was increased by solid manure and compost. The increase appeared to be due to an increase in the grass component of the stand in plots where the manure or compost was applied.

At the time of the second cut of hay in 1990, alfalfa was the dominant species harvested but there were no significant differences in total yield of hay. Similarly, in the third cut there were no significant differences. When totalled over the second year, the fertility treatments increased the alfalfa yield and the total forage yield. The solid manure application increased the forage yield the most - both grass and legume growth were increased in 1990.

Soil nutrient levels, measured by laboratory soil tests, declined throughout the course of the study (P and K) under all fertility management. The solid manure or fertilizer might be able to maintain soil nutrient levels during the stand's life, provided initial levels were medium or high. In this study, application of fertilizer and solid manure resulted in higher P levels by the end of the second year compared with zero applications.

Rainfall simulation indicated that with the high degree of ground cover (approaching 100%), and the dry soil condition, the manure management used did not appear to pose a problem from the perspective of P and soil runoff losses.

E.4.5 Response of Farming Systems to Various Sources of Fertilizer Phosphorus

(SWEEP Report No. 23)

There is considerable interest in understanding organic and low input farming systems. Researchers and producers question whether a system which is " conventional" and has received inputs of fertilizers, chemicals, tillage, and no cover crop or green manures, will differ in the processes involved in plant nutrition, compared with a system which has received fewer or none of such inputs.

A premise of the study is that organic systems will rely on biological processes while such processes will be inoperative or hidden in a conventional, input-intensive system. It is proposed that biological processes may operate in systems without chemical inputs.

Research has found several examples of processes disrupted by cultural methods.

1. Nitrogen fertilizers inhibit N_2 fixation in legumes (Marschner, 1986 in SWEEP Report No. 23)
2. P fertilizers inhibit mychorrizal infection and phosphatase activity (Smith and Gianninazzi-Pearson, 1988 and Spiers and McGill, 1979 in SWEEP Report No. 23).
3. Disturbance of soil such as by tillage reduces the effectiveness of mychorrizal infections. Results of recent research suggest that the P concentration of the plant, and not the availability of soil P influences the extent of

mycorrhizal infection (1990 Annual Report, LRS pp. 46-48).

It is proposed that the processes affecting the *mobilization and uptake of P* may vary between different farming systems because of variations in management practices, types and rates of applications of inorganic and organic fertilizers, and in cropping sequences.

The study examined crop success, and selected biological processes in conventional and organic farms from the use of various fertilizers. Particularly, several experiments examined compost and rock phosphate as sources of fertilizer phosphorus, hypothesizing that one system would have a better ability to use these sources, than another due to enhanced mobilization of phosphorus. Farms examined in the study ranged from long term organic (20 years) to moderately intensive conventional. Soil and crop parameters examined included soil fertility (P, K, Ca, Mg, and pH); plant nutrition (N, P, K, Ca, Mg in crop and green manures); crop yield; weed biomass; mycorrhizal infection (fungi involved in P absorption); and, root and soil phosphatase activity (involved in cycling and absorption of P).

From a two year study comparing three organic and three conventional farms:

1. There were no pronounced differences between farming systems (organic vs. conventional) in response to different types of fertilizers (rock P, compost, super phosphate). There was no significant effect on total P in crop plants at harvest in 1988. Soil P levels increased on some farms with superphosphate and compost, whereas rock P had no effect on soil P levels.
2. Soil phosphatase activity was no different on organic vs. conventional farms according to the P source.
3. Percent mychorrizal infection was not related to farming system and was not related to soil P or plant P in young plants.

Several experiments studied processes on a long term organic farm:

4. A study over several years on one long term organic farm showed discing and leaving straw increased soil P measured by resin in 1988 (compost and super P also increased soil resin P), but not when measured by Na-bicarbonate extraction, while either moldboard or discing with straw removed had no effect. Discing plus straw increased soil phosphatase activity.
5. Green manure crops had no effect on crop nutrient level, mycorrhizal infection or phosphatase activity.
6. There was no response of oats to the application of rock P even though soil resin P levels increased one year after its application.
7. There was an increase in N and P in oat grains in response to the green manure, faba beans.
8. The incorporation of oat hulls, which was an organic C addition, to a legume crop resulted in lower soil nitrate levels, higher N_2 fixation rates, greater vetch biomass production and fewer weeds.
9. Although nutrient concentrations in vetch tissue were not affected by the carbon additions, the total nutrients (N, P, K, Ca) accumulated by vetch biomass were highest under the effect of oat hulls. Since the additional nutrients could not be accounted for in the oat hulls, it is concluded that the oat hulls stimulated plant growth other than through the addition of nutrients.

In summary, the study showed no pronounced differences in the modes of action in conventional and organic systems. However, it is known that soil microbes use organic-C additions as an energy source and they will become more active and carry out appropriate conversions. Green manures do not appear to contribute to enhanced P nutrition of the plant through enhanced fungal infection or phosphatase activity on organic farms.

E.4.6 NUTRIENT DISTRIBUTION AND STRATIFICATION RESULTING FROM CONSERVATION FARMING

(SWEEP REPORT NO. 35)

This TED study was initiated to gain a better understanding of the extent and severity of nutrient stratification in Ontario soils. There is a concern that, when fertilizer is broadcasted in a conservation tillage system, there is a tendency for phosphorus to remain at or near the surface of the soil, resulting in vertical stratification and the possibility of phosphorus enriched runoff. Fertilizer banding may lead to horizontal stratification of nutrients, which could lead to errors when using the soil test to determine fertilizer requirements.

The first experiment of the study examined vertical stratification by comparing soils under conservation and conventional tillage at 36 sites, covering a wide range of soil textural groups. The soil was sampled at 2 cm increments to a depth of 20 cm, and then at 5 cm increments to a depth of 45 cm. Samples were analyzed for plant-available P, K, Mg and Ca along with pH and organic matter. Measurements of soil physical properties, including bulk density, cone penetrometer resistance and infiltration rates, were also made at most of the sites. A questionnaire was given to each farmer cooperator requesting information on the management history of the field. This information was used to classify the tillage system as conventional, reduced or no-till.

Nutrient data were grouped into three strata (0-10 cm, 10-20 cm and 20-45 cm) to correspond to the average depths of secondary and primary tillage, and the layer below primary tillage. The data were categorized according to tillage system and soil type (clay, loam, sand).

Analysis of the data showed that nutrients were evenly distributed within the plow layer of the conventionally tilled soils, while the no-till soils showed a significantly greater rate of decline in nutrient levels with depth. Soil organic matter was also stratified with depth under no-till management. Results from the reduced tillage fields were inconsistent, due to the wide range of tillage practices which were included in this category.

Soil texture also affected the vertical stratification of nutrients. Greater infiltration rates in the sandy soils enhanced the leaching of nutrients and reduced the degree of nutrient stratification in the no-till soils.

The second experiment of the study dealt with horizontal stratification of soil nutrients, pH and organic matter. Nine no-till sites were included in the investigation, three from each soil textural group. All of the sites had a history of fertilizer application by banding. Soil samples were taken from a 100 cm transect perpendicular to the crop rows, at 20 cm intervals and at 2 cm depth increments to a depth of 20 cm. Analysis of the samples was similar to that conducted in the vertical stratification experiment.

A significant correlation was found between the number of years that a field had been managed under no-till and the horizontal variation in nutrient concentrations, with the long term no-till having the greatest amount of differences in the concentration across the rows. Soil texture significantly affected the severity of horizontal stratification of K, Mg and to a lesser extent, P. Phosphorus stratification was significantly affected by sample depth, with the greatest variation in P concentrations occurring at a depth of 6 cm. Thus, the location of the sampling site with respect to crop rows must be considered when collecting composite soil samples for a soil test on farms under no-till management.

The study results indicated that no-till management does lead to nutrient stratification, particularly in heavier textured soils, and that the stratification appears to increase with the number of years of no-till. However, the results were highly variable, and could have been influenced by a wide range of factors, including the timing of the field sampling operations, which occurred over a four month period in 1989, and the amount, timing and method of fertilizer application, which were different for each site. Considerably more than the one field season of measurements offered by this study would be required to fully understand the complex relationships between nutrient stratification and conservation farming.

E.5 PEST CONTROL

E.5.1 CONTROL OF PROBLEM WEED SPECIES

(SWEEP REPORTS NO. 19 AND 19A; PROGRESS BULLETIN ISSUE 14)

Farmer perception that new and exacerbated weed problems occur when tillage is no longer available as a method of weed control was cited as a barrier to the adoption of reduced and zero tillage systems. Over time, as farm management practices change from conventional tillage to conservation tillage, weed communities may change. These changes may appear as differences in types of weeds, densities of weeds or as differing times of weed emergence.

A study was conducted in 1988-89 to examine the weed spectrum and control of problem weed species. The study consisted of a weed, and herbicide use survey, as well as a study of developmental stages (phenology) of weeds relative to tillage type, and the effects of placement and mechanical damage of weeds on their reproduction and growth.

WEED SURVEY

From mid-July to mid-August 1988 and 1989, 593 fields with six different soil textures were surveyed in eleven counties over Southwestern Ontario (Essex, Kent, Lambton, Elgin, Middlesex, Huron, Perth, Oxford, wellington, Waterloo and Brant). In each field, twenty 0.25 m^2 quadrats were examined for weed number and species. Numbers were recorded and comparisons were made among tillage system (conventional, conservation, no-till), crop type (corn, soybeans, wheat or forage) and period of transition into tillage type (1st year called 1st year, 2nd or 3rd called transitional, 4 years or more in the current tillage practice was called established).

The survey showed that five weed species dominated in 25% or more of all the fields observed. These weeds were green foxtail, lamb's-quarters, quack grass, redroot pigweed, common ragweed and dandelion. Tillage system had no significant impact on the numbers of species present in a field. There were 61 species identified in conventional tillage systems, 69 in conservation tillage systems, and 68 in no-till systems.

Density of weeds varied between the different tillage systems. First year conservation till fields generally had greater densities of annual and perennial grasses than conventional till fields. The frequency and density of annual weeds were generally higher in no-till fields than in conventional or established conservation till fields. This is perhaps partly due to scuffling in conventional and conservation till fields. Frequency of dandelion was higher in no-till fields when compared to conventional till fields. As no-till became established, dandelion density in no-till fields dropped. Quack grass decreased in frequency and density as no-till became established and had lower density of quack grass than conservation tillage fields.

There were no large differences in weed communities between fields that differed in current crop, previous crop or crop rotation. Most weed species were common to all cropping systems.

Cropping history influenced weed frequencies. Dandelion and quack grass often occurred in fields where perennial crop species were grown in the past. Horse tail often occurred where continuous corn was grown in the past. These corn fields also had a high density of grass weeds. Fields that had a history of mixed crops (excluding perennials), generally had lower frequencies of annual grasses.

Geographic location influenced weed populations. The above-mentioned six species that were found in >25% of the fields were common in all geographic locations. Other species such as wild carrot, Canada thistle, broad-leaved plantain, prostrate knotweed, yellow foxtail, barnyard grass, crab grasses, witch grass, field horsetail and fall panicum were found in relatively low frequency throughout the entire survey area. Velvet leaf and eastern black nightshade were found at moderate frequencies in the extreme southwest. These frequencies suggest that their distribution is limited and that they were recently introduced. Wild buckwheat was found more frequently in the north to less frequently in the south of the study area. Dandelion was very abundant in the eastern sections of the survey which reflects the greater incidence of dairy farms in that area. Dairy farms generally have rotations including forage perennials. Field bindweed and common milkweed appeared in higher frequency in Perth, Huron and Middlesex counties.

WEED PHENOLOGY

Control of weeds is related to the developmental stage of the crop and weed species. It is generally advantageous to control germinating or emerging weeds rather than flowering or fruiting weeds. Therefore, it is useful to know when different developmental stages occur.

A subset of the surveyed fields was used to examine weed frequency, density and height in each of four monitoring periods: May prior to the planting of corn or soybeans,

June prior to post emergence herbicide application, July after most weed control measures were complete and August when weeds were mature. The study extended to the counties of Essex, Kent, Lambton, Middlesex, Huron, Perth, and Elgin and focused on weeds occurring in corn, soybeans and winter wheat in the three different tillage practices.

The different crop development stages occurred at similar times in all three tillage systems. Of the eleven species of weeds that were studied, the density, height and timing of reproduction of lamb's quarters, redroot pigweed and velvet leaf did not vary with tillage type. The eight other weed species varied in terms of crop type and monitoring period.

Overall, dandelions flowered most often in no-till fields. Dandelions did not flower in conventional corn fields and they were absent in conventional winter wheat fields.

In corn fields, annual weeds reproduced somewhat earlier in the no-till than in either the conservation or the conventional tillage systems.

In soybean fields, during early monitoring, common ragweed was the most abundant annual weed in conservation tillage systems. Ragweed was less abundant in the no-till systems. Other annual weeds were at similar height and density at the different phenological stages. Later in the growing season, there were no differences in the weed frequency or density between tillage systems in soybeans.

Conventional tillage fields of winter wheat had the fewest weeds at all monitoring times, compared with the other tillage systems. However, conventional fields did have greater numbers of field bindweed throughout the growing season. During June and July, the bindweed was also larger in conventional tillage fields.

Chemical Control

Reduced tillage generally provides more crop residue on the soil surface and less mechanical weed control. The use of herbicides to control weeds in a reduced tillage system could potentially pose problems. Surface trash may intercept herbicides, thus preventing the chemical from reaching their target.

Herbicide use patterns were examined using questionnaire data. Farmers were asked about their weed control, cropping practice and herbicide efficacy. Results from this study suggest a decreased use of soil incorporated herbicides and an increased use in burndown herbicides. The increased use in burndown herbicide is limited to the few that are currently registered. There also was an increase in spot herbicide treatments in conservation tillage and in no-tillage systems. Overall, there was a very slight increase in herbicide usage in conservation tillage and in zero tillage compared to conventional tillage.

Placement

Trials were set up at the Harrow Research Station to study how burial depth of propagules and mechanical damage will affect weed growth. Weed seeds of the following species were used: barnyard grass, broad-leaved plantain, Canada thistle, dandelion, fall panicum, giant foxtail, green foxtail, lamb's-quarters, large crab grass, common milkweed, eastern black nightshade, common ragweed, redroot pigweed, lady's thumb, stinkweed, velvetleaf, wild buckwheat and wild carrot. Dandelion roots, yellow nut sedge tubers, and rhizomes of field bindweed and quack grass were also used. Propagules were buried in the ground early in December, at depths of 7.5cm and 15cm. In April, the propagules were retrieved and compared to fresh propagules for viability, germination, and sprouting ability.

Viability of most propagules did not decrease over the winter, regardless of burial depth. Viability of large crab grass seeds (annual grass) and some perennial broad leaves (Canada thistle, dandelion, and common milkweed) did decrease over the winter. The increased viability of common ragweed, lady's thumb and giant foxtail suggests that overwintering seed may be less likely to rot.

Germination ability increased over the winter for most annual species except large crab grass and stink weed. Germination ability also increased for the perennial broad-leaved plants, common milkweed and broad-leaved plantain, but decreased for Canada thistle and dandelion.

Generally, with greater depth of burial, the survival of propagules such as dandelion, milkweed and nutsedge increased as compared to the soil surface. Quack grass sprouted equally well regardless of the depth of burial. Field bindweed did not survive well at any depth.

Mechanical Damage

Twelve species of weeds were subjected to different types of mechanical damage in the greenhouse. These weeds included species that occurred in the greatest numbers in reduced tillage systems (green foxtail, lamb's-quarters, quack grass, field bindweed, redroot pigweed, common ragweed, dandelion, barnyard grass, common milkweed, yellow nutsedge, velvetleaf and wild carrot). The weeds were planted in greenhouse flats which represented field conditions. Once the roots of each species were established, one of four treatments were applied: roots

were severed 2cm below soil surface, roots were severed 15cm below soil surface, a 15cm plug of rooted soil was inverted or soil was left undisturbed. Ten weeks after treatment, the weed plants were checked for survival, and the survivors were dried and weighed.

Overall, annual weed survival was lower than perennial weed survival after mechanical damage. The timing of mechanical damage did not effect the survival of the annual weeds. Shallow cutting or inversion most severely affected annual weed survival (barnyard grass, green foxtail, common ragweed, redroot pigweed, lamb's-quarters and velvetleaf). Similarly, the shallow cutting and the inversion treatments had the most adverse effect on perennial weed survival. Deep root cutting rarely affected the survival of dandelion or yellow nutsedge. Timing of mechanical tillage did affect survival of perennials. If damage occurred three to four weeks after planting, survival was adversely affected. In general, biomass of annual plants was reduced only after shallow cutting at two weeks. Later treatments to roots of perennial weeds generally affect weed biomass.

CONCLUSIONS

- In general, similar weed species were found in all three tillage systems although the conventional system had slightly less dense weed populations. Overall, weeds that were a problem in one tillage system were a problem in all three tillage systems.
- Weed development (phenology) was similar in all three tillage systems. There was some evidence of more uniform development of perennials in no-till fields compared with conventional fields which suggests easier herbicide control.
- Usage of soil incorporated herbicides decreased with reduced tillage whereas usage of burndown and spot treatment herbicides increased with reduced tillage.
- Burial of weed propagules tended to favour survival of annuals over perennials. Also, perennial species survival is reduced the closer they are to the surface or when they are mechanically damaged soon after their emergence.

This study suggests that there is not necessarily an increased weed problem with reduced tillage. It also suggests that tillage systems are not the only regulators of weed intensity; there are many management factors involved.

E.5.2 OPTIMAL HERBICIDE USE IN CONSERVATION TILLAGE SYSTEMS

(SWEEP REPORT NO. 32)

Over the years 1987 to 1990 field studies were carried out with the objective of developing weed control recommendations for farmers in conservation tillage. The study concluded that weed control in conservation tillage systems did not require higher herbicide dosages despite the presence of crop residues on the soil surface. Perennial weeds were effectively controlled and were considered to not pose a threat to crop production in conservation tillage. Banded herbicide applications in conjunction with inter-row cultivation and reduced herbicide dosage can be used in an integrated weed management system for no-till corn.

The report of this study contains considerable information on weed control in many systems tested over the several plot-years. The recommendations of the report are reproduced here to serve as summary of the findings. They are described for each major set of experiments.

BURNDOWN AND RESIDUAL HERBICIDES FOR LEGUME AND CEREAL COVER CROP PLANTED IN CORN AND SOYBEANS

On the basis of field experiments conducted at different sites from 1987 to 1990 the following recommendations are suggested for burndown of cover crops in no-till crop production systems:

Soybeans

Alfalfa burndown

Spring applied tank-mixture of glyphosate at 0.90 kg ha^{-1} + 2,4-D (amine or ester) at 1.0 kg ha^{-1} can provide excellent established alfalfa control. The dandelion may be more efficiently controlled by the ester formulation of 2,4-D.

Winter wheat

For control of winter wheat, apply glyphosate at 0.45 to 0.90 kg ha^{-1} or paraquat at 1.0 kg ha^{-1} to wheat seedlings up to 4 leaf stage of growth.

Winter Wheat Burndown with Glyphosate

Winter wheat burndown was found to be dependent upon the growth stage of wheat at the time of herbicide application, herbicide dose and additives. Apply glyphosate at 0.30 kg ha^{-1} + ammonium sulphate at 2 l ha^{-1} + Agral 90 at 0.1% (v/v) to winter wheat seedlings in 2 to 3 leaf (12-14 cm tall) stage of the growth.

Corn

Red Clover Burndown

The following herbicides are recommended for established red clover burndown in corn. These herbicides should be tank-mixed with 1% (v/v) Komoil concentrate.

- 2,4-D (ester or amine) at 0.50 to 1.0 kg ha^{-1} + atrazine at 1.50 kg ha^{-1} + metolachlor at 1.92 kg ha^{-1} before the emergence of corn.
- Glufosinate at 1.0 kg ha^{-1} + metolachlor at 1.68 kg ha^{-1} + atrazine at 1.50 kg ha^{-1} or dicamba at 0.60 kg ha^{-1} applied preemergence to corn.
- Paraquat at 1.0 kg ha^{-1} + metolachlor at 1.68 kg ha^{-1} + atrazine at 1.50 kg ha^{-1} or dicamba at 0.60 kg ha^{-1} applied preemergence to corn.
- Dicamba at 0.60 kg ha^{-1} + atrazine at 1.50 kg ha^{-1} + metolachlor at 1.92 kg ha^{-1} preemergence to corn.
- Glyphosate at 0.90 kg ha^{-1} followed by metolachlor at 1.68 kg ha^{-1} + atrazine at 1.50 kg ha^{-1} or dicamba at 0.60 kg ha^{-1}.

Precaution: Glyphosate was applied as pre-split with metolachlor + atrazine or dicamba.

Alfalfa burndown

- Apply glyphosate at 1.5 kg ha^{-1} in the fall followed by a spring application of atrazine at 2.0 kg ha^{-1}.
- Apply atrazine at 2.0 kg ha^{-1} in the fall and again at 2.0 kg ha^{-1} the following spring.
- Dicamba at 0.6 kg ha^{-1} + atrazine at 2.0 kg ha^{-1} applied in the spring prior to the corn planting.
- 2,4-D/mecoprop/dicamba at 1.1 kg ha^{-1} + atrazine at 2.0 kg ha^{-1} applied in the spring prior to the corn planting.
- Glufosinate at 1.5 kg ha^{-1} in the fall followed by a spring application of atrazine at 2.0 kg ha^{-1} or as a tank-mix of glufosinate + atrazine applied in the spring prior to corn planting.

ANTAGONISM OF BURNDOWN HERBICIDES WITH RESIDUAL HERBICIDES IN CONSERVATION TILLAGE SYSTEMS

On the basis of field experiments conducted at different sites from 1987 to 1990 the following recommendations are suggested for tank-mixing of various burndown and residual herbicides in no-till crop production systems:

Paraquat and Glufosinate Antagonism with Residual Herbicides in Corn

- Paraquat at 0.5 kg ha^{-1} can be tank-mixed with recommended label rates of metolachlor + atrazine (WP or liquid) or cyanazine (WP or liquid) for annual weed control in corn.
- Glufosinate (0.5 to 0.75 kg ha^{-1}) can be tank-mixed with recommended label rates of metolachlor + atrazine WG for annual weed control in corn.

Glyphosate Antagonism with Residual Herbicides in the Presence of Additives in No-till Corn

- Glyphosate from 0.30 to 0.90 kg ha^{-1} + ammonium sulphate at 0.2% (v/v) + Agral 90 at 0.5% (v/v) may be tank-mixed with metolachlor + atrazine, cyanazine, or dicamba at labelled rates for weed burndown and residual control of annual weeds in corn.

Paraquat and Glufosinate Antagonism with Residual Herbicides in Soybeans

- Paraquat at 0.5 kg ha^{-1} can be tank-mixed with recommended label rates of metolachlor + metribuzin or linuron for annual weed burndown and subsequent residual weed control.
- Glufosinate at 0.50 to 0.75 kg ha^{-1} can be tank-mixed with recommended labelled rates of metolachlor + metribuzin or linuron for annual weed burndown and subsequent residual weed control.

Glyphosate Antagonism with Residual Herbicides in the Presence of Additives in No-till Soybeans

- Glyphosate from 0.45 to 0.90 kg ha^{-1} + ammonium sulphate at 2 l ha^{-1} + Agral 90 at 0.1% (v/v) may be tank-mixed with residual herbicides metolachlor + metribuzin or linuron at labelled rates for burndown and residual control of annual weeds in soybeans.

Antagonism of Paraquat, Glyphosate and Glufosinate with Various Residual Herbicides for Quackgrass Control

- The herbicidal activity of glyphosate was antagonized with tank-mixtures of linuron (L), atrazine (DF), metribuzin (DF), dicamba or 2,4-D in amine or ester salts at recommended labelled rates.
- The herbicidal activity of glyphosate was synergized when tank-mixed with metolachlor at recommended labelled rates.
- The herbicidal activity of paraquat was antagonized with tank-mixtures of linuron (L) or 2,4-D in amine or ester salts at recommended labelled rates.
- The dose of paraquat can be reduced to 0.50 kg ha^{-1} from 1.0 kg ha^{-1} if tank-mixed with atrazine, metolachlor or metribuzin at currently recommended rates.
- The herbicidal activity of glufosinate was antagonized with tank-mixtures of linuron (L), dicamba or amine salt of 2,4-D at recommended labelled rates.
- The herbicidal activity of glufosinate was synergized when tank-mixed with atrazine IDF), metribuzin (DF), metolachlor or ester salt of 2,4-D at recommended labelled rates.

Impact of Tank-Mixes of Burndown and Residual Herbicides with Additives on Weed Control in Conservation Tillage Systems

On the basis of field experiments conducted at various sites from 1987 to 1990 the following recommendations are suggested for the use of additives with various residual and burndown herbicides in no-till crop management systems.

The Role of Additives with Residual Herbicides in No-till Corn

- Metolachlor + atrazine or metolachlor + atrazine + dicamba at labelled rates may be sprayed with additives Agral 90 at 0.1% (v/v), Kornoil concentrate at 1% (v/v), Kornoil at 10 l ha^{-1}, 28% N at 500 l ha^{-1}, 10-34-0 at 10 l ha^{-1}, Aqua 21% N at 10 l ha^{-1} for burndown and residual annual weed control in corn.

Herbicides for Burndown and Residual Control of Annual Weeds in No-till Corn

- Atrazine at 1.5 kg ha^{-1}, cyanazine at 2.5 kg ha^{-1} or atrazine at 1.5 kg ha^{-1} + cyanazine at 2.5 kg ha^{-1} with 1% solution (v/v) or Kornoil concentrate.
- Linuron at 1 kg ha^{-1} + metribuzin at 0.5 kg ha^{-1} or linuron at 1 kg ha^{-1} + atrazine (1 kg ha^{-1}) + metolachlor (2.4 kg ha^{-1}) with 1% Kornoil concentrate.
- Glufosinate at 0.75 kg ha^{-1} + metribuzin at 0.75 kg ha^{-1} with 1% solution (v/v) of Kornoil concentrate.

Annual Weed Control in No-till Corn by Residual Herbicides Applied with Additives

- For control of common ragweed seedlings, atrazine, cyanazine, linuron or dicamba at labelled rates, applied preemergence to corn.
- Additives such as 28% N at 5% (v/v) or Kornoil concentrate at 1% (v/v) may be added with these herbicides.

Burndown and Residual Weed Control in No-till Soybeans

- Metolachlor (2.4 kg ha^{-1}) + metribuzin (0.6 kg ha^{-1}) should be applied with additives 28% N or 10-34-0 at 10 l ha^{-1} for effective annual weed control in soybeans.
- Metolachlor at 2.4 kg ha^{-1} + linuron at 2 kg ha^{-1} should be applied with additives Agral 90 at 0.1% (v/v), 10-34-0 at 10 l ha^{-1}, or Liquid cyanamid at 10 l ha^{-1} for effective annual weed control in soybeans.
- Metolachlor at 2.4 kg ha^{-1} + monolinuron at 2 kg ha^{-1} should be applied with additive Kornoil concentrate at 1% (v/v), oil at 10 l ha^{-1}, 28% N at 10 l ha^{-1} or Liquid cyanamid at 10 l ha^{-1} for effective annual weed control in soybeans.

Annual Weed Control in No-till Soybeans by Residual Herbicides Applied with Additives

- Linuron, metribuzin and imazethapyr do not require additives such as Kornoil concentrate at 1% (v/v) or 28% N solution at 5% (v/v) to control common ragweed.

- Ragweed control by metolachlor + linuron or metribuzin increases in the presence of additive 28% N at 5% (v/v).

Preemergence and Postemergence Herbicides for Control of Quackgrass

- Glyphosate dosage may be reduced from 1.8 kg ha^{-1} to 0.9 kg ha^{-1} if applied with additive Frigate at 0.5% (v/v).
- Glyphosate dosage may be reduced from 1.8 kg ha^{-1} to 0.45 kg ha^{-1} if applied with additives Frigate at 0.5% (v/v) + Ammonium Sulphate at 3 l ha^{-1}

Integrated Weed Management in No-Till Cropping Systems

On the basis of field experiments conducted at various sites from 1987 to 1990 the following recommendations are suggested for the integrated weed management in corn and use of 2,4-D in soybeans in no-till crop management systems.

Tillage 2000: Preemergence Herbicides for Annual Weed Control in Various Tillage Systems

- Currently registered herbicides at labelled rates provide similar weed control in all tillage systems (no-till, ridge tillage, chisel or moldboard plough).
- There is no justification for increasing herbicide dosages in any given tillage system in corn.

Quackgrass Control in No-till Corn

- Under no-till system 82% of quackgrass rhizomes were found within the top 7.5 cm of soil surface.
- Apply glyphosate at 0.9 kg ha^{-1} in the spring to actively growing quackgrass in the 3 to 5 leaf stage of growth.

Residual Effect of 2,4-D on Soybeans

- Apply 2,4-D ester or amine formulation at 0.5 to 1.5 kg ha^{-1} two weeks prior to soybean planting or apply 2,4-D ester formulation only, one week prior to soybean planting.

E.5.3 Feasibility of Band Spray Application in Conjunction with Inter-row Cultivation in No-Till Corn

(SWEEP Report No. 48)

Over the three years, 1989 through 1991, experiments were carried out to test the feasibility of band spraying of herbicides plus mechanical weed control technology in no-till crop production. The system, which has been effective in ridge tillage, can reduce herbicide use by as much as 65% by banding instead of broadcasting, and relies on timely removal of weeds from between crop rows using cultivators that perform in conditions of heavy crop residues.

The authors define the weed management system of the traditional no-till grower: a non-residual burndown herbicide is applied, the crop is seeded, either a preemergent and /or postemergent herbicide(s) is applied to control the weeds that emerge after the burndown application. Weed control is thus dependent on selecting the most appropriate herbicide for the crop and weed spectrum, and applying it correctly and at the right time.

The efficacy of cultivation (Experiment I), and various preemergence (Experiment II) and postemergence (Experiment III) herbicides were tested within the reduced tillage corn system. A fourth experiment tested the weed management system under field scale conditions in order to assess its usefulness to no-till farmers.

Experiment I

The objective was to determine whether the use of heavy duty cultivators had a beneficial effect on reduced -tillage corn production and whether the use of cultivation in conjunction with banded herbicide application compared with weed control obtained with strategies that rely almost entirely on herbicides.

Experiments were conducted in 1990 and 1991 at Ridgetown on clay loam soils. The sites received a burndown of glyphosate, Agral 90 and ammonium sulfate. The sites were planted to corn. Herbicide treatments were either broadcast or banded (30 cm band). Two dose levels of metolachlor and cyanazine were used. Plots received either 0, 1, or 2 inter-row cultivations achieved with a Buffalo heavy duty 4-row cultivator with sweeps and hiller-disc at 4 to 6 cm deep. Control plots were weeded and weedy checks received the cultivation treatments (0, 1, and 2 times).

In either year cultivation alone had no effect on corn yields. Cultivation alone provided about 75% control of broadleaf weeds and grasses in one pass, and 90-95% control of annual weeds in 2 passes. This control was considered high and was attributed to low weed pressure and drought.

Low application rates provided similar weed control to the higher rates under either method of application. Herbicide banding followed by one or two passes with the cultivator provided weed control comparable to the overall broadcast applications.

The cultivator penetrated the soil, maintained its depth, left the soil surface reasonably level, and allowed crop residue to remain on the surface for erosion control.

EXPERIMENT II

The objective was to evaluate preemergent herbicide band application in combination with inter-row cultivation in reduced tillage corn.

Field experiments were carried out in 19 -89, -90, and -91 on clay, clay loam, and loam soils. Burndown of glyphosate or glyphosate plus 2,4-D was used if required. Band applications were applied in a 30 cm band.

The 1989 crop year was dry, corn yields were low and the herbicide treatments had no effect on yields. In the following year, several weed control treatments improved yields above the weedy check although none improved yields relative to the weeded plots.

Most herbicides provided good to excellent control of annual broadleaf weeds and grasses. Some herbicides failed to provide adequate control of redroot pigweed and lamb's quarter (dicamba @0.6 kg/ha; cyanazine + dicamba @ 2.25 + 0.6 kg/ha), fall panicum (linuron + atrazine @ 1.1 + 1.1 kg/ha), and foxtail (metribuzin @ 0.75 kg/ha) in 1990. Weed escapes occurred mostly in the crop row with cultivation providing very good control in the inter-row area.

It was concluded that band application of preemergent herbicides plus shallow inter-row cultivation provides weed control comparable to broadcast applications of herbicides.

EXPERIMENT III

An experiment similar to the one described above evaluated the band application of postemergent herbicides plus shallow inter-row cultivation in reduced tillage corn.

Corn yields were unaffected in 1989 and 1990 by the weed control systems. In these years all herbicides provided good to excellent annual weed control. A banded application of atrazine/dicamba followed by one inter-row cultivation performed as well as the overall application.

EXPERIMENT IV

Both pre- and post- emergent herbicide treatments were banded and integrated with inter-row cultivation in a reduced tillage corn system. This experiment used grower's equipment and was carried out at a field scale. A Kinze 6-row planter was used for seeding. A 6-row wide heavy duty cultivator, equipped with nitrogen sidedressing accessories and a postemergence herbicide kit was used to cultivate, sidedress and apply postemergence herbicide on each row of the crop. Each plot received metolachlor in a 30 cm band applied over the row with the planter. In each year a burndown of glyphosate was used. Broadcast applications were applied with a field sprayer while banded applications were applied with the cultivator during second cultivation in corn.

All banded applications in conjunction with two inter-row cultivations provided corn yields similar to the overall broadcast herbicide applications. In particular, the two cultivations provided excellent weed control between rows and the split application of metolachlor applied preemergently then postemergently in a band provided broad spectrum weed control comparable to herbicide applications overall.

The farm operator found the benefits of the banding/interrow cultivation system of weed control to include a cost savings in herbicides of $17/acre. Herbicide use was reduced 60% in this system. The potential drawbacks related to the inter-row cultivation disturbance of the soil structure and root pruning. These appeared to outweigh the benefits. Two cultivations appear to be required in the system.

E.6 WATER MANAGEMENT

E.6.1 THE EFFECTS OF TERRACES ON PHOSPHORUS MOVEMENT

(SWEEP REPORT NO. 14)

A channel terrace, sometimes known as a WASCOB (Water and Sediment Control Basin), is an earthen berm spanning a natural draw. Channel terraces intercept and temporarily pond runoff water originating from small watersheds. While the water is held back, some of the sediment is removed through settling. Ponded water is released at a controlled rate through a standpipe inlet connected to the subsurface drainage system.

A pilot study was commissioned by TED to develop an appropriate method for monitoring a channel terrace, and to evaluate the impact of channel terraces on sediment and phosphorus losses from rolling crop lands. An additional goal was to document the equipment and techniques necessary for investigating the effectiveness of terraces.

Project tasks included site selection, the development of a monitoring strategy, testing of monitoring equipment in the lab, installation of equipment in the field, collection and analysis of field data and further analysis of the results through the use of computer simulation models.

The channel terrace selected for the study was constructed in 1982 on a farm in Huron County. Soils in the field surrounding the terrace were analyzed for texture, organic matter content and saturated hydraulic conductivity. Measurements of phosphorus content in the top 1 cm of the soil profile were also taken. The watershed was surveyed and a 0.25 metre contour interval site map prepared to define the boundaries of the 2.4 ha (5.9 acre) area contributing runoff. The survey information was also used in the development of a stage-storage relationship for the sediment basin.

A concrete catch basin was installed near the Hickenbottom® surface inlet of the terrace to house the monitoring instruments and provide access to the subsurface tile line. Precipitation at the site was measured using a tipping-bucket rain gauge. A paddle wheel flow sensor was installed in the 100 mm (4") diameter outlet pipe and a pressure transducer recorded the depth of ponded water in the terrace. Digital output from the rain gauge, flow sensor and pressure transducer was recorded on a datalogger.

An ISCO® automatic water quality sampler was installed in the catch basin and programmed to collect samples of runoff water from the terrace outflow pipe during runoff events. Water samples were analyzed for total suspended solids as well as total and soluble phosphorus.

An array of sediment cups at 3.3 x 3.3 metre spacing was set up near the surface inlet. Sediment cups were made of 76 mm (3") diameter ABS pipe, cut into lengths of 125 mm (5"). Each cup was fitted with a screen and filter paper, then placed in the ground to a depth of 62 mm (2.5"). An estimate of the amount of sediment that had settled out of the runoff water during ponding could be obtained by collecting the sediment from the filter paper in each cup after a rainfall event. The terrace's efficiency at trapping sediment could be estimated by correlating the amount of sediment in the cups to the sediment measured in the runoff water collected by the automatic sampler.

The study site was monitored from April to November, 1989. The white bean crop grown during the 1989 season was expected to yield runoff that was relatively high in suspended sediment due to the large amount of bare soil associated with this crop.

A hydrologic model, HYMO, and three soil erosion computer models, AGNPS, CREAMS and SEDCAD+ were applied to the study site. HYMO was used to obtain hydrologic parameters necessary for the other three models. SEDCAD+ contained some advanced algorithms for simulating the process of sedimentation in ponds. Only AGNPS and CREAMS had the capacity to model the efficiency of sediment basins with respect to nutrients such as phosphorus.

A conclusive evaluation of terrace effectiveness was not possible due to a lack of major rainfall events in Huron County during the 1989 season. Only one storm was sufficient to generate runoff and ponding at the site. Results from that storm were incomplete, due to equipment malfunction. However, the equipment that worked properly provided a partial storm data set from which the missing data could be interpolated.

Based on the amount of sediment found in the sediment cups and that which was measured in the outflow sample, the sediment trapping efficiency of the terrace was between 12 and 21%. The phosphorus trapping efficiency was estimated at 9 to 17%. Sediment trapping efficiencies of up to 97% have been reported by researchers in the United States. It was suggested that the terrace in this study had a lower efficiency because the surface inlet was set for a high outflow rate which did not allow much sedimentation to occur. Water in the terrace was ponded

for a maximum of two hours, with most of it passing through in less than one hour. Thus, the terrace was acting more like a tile/catchbasin system than a sediment basin.

Accurate calibration of the simulation models was difficult since field measured runoff data were available for only one storm event. All of the models indicated that the effectiveness of the channel terrace in controlling erosion would increase as the magnitude of the rainfall event increased.

Optimum ponding time was identified as the key factor in the design of a channel terrace system. Water must remain in the terrace long enough to remove most of the sediment while avoiding damage to the field crop due to prolonged flooding. Factors which the designer must consider are the size of the orifice plates that control flow rates through the surface inlet, the infiltration capacity of the soils at the site and the sensitivity of the crop to periods of ponding.

Only one rainfall event large enough to generate surface runoff occurred during the study period, despite a six month extension to the monitoring contract. Thus, no substantial conclusions could be drawn about the effectiveness of channel terrace structures in reducing sediment and phosphorus loads to streams. However, a detailed methodology for conducting a terrace monitoring study was developed and documented in the report. This information should prove useful for others attempting to continue work in this line of research.

E.6.2 Effects of Management on Surface Hydraulic Properties

(SWEEP Report No. 18)

The Guelph Pressure Infiltrometer (GPI) was used to obtain measurements of the surface hydraulic properties of soils under conservation and conventional tillage systems. The GPI provides measurements at the field which are faster, less destructive, and ultimately more useful to farmers than laboratory soil tests.

The GPI measures field saturated hydraulic conductivity (K_{fs}), matric flux potential (ϕ_m), and other soil hydraulic properties. The K_{fs} values obtained from the GPI have been found to correlate significantly with the more labour intensive and slower undisturbed core laboratory method. The GPI can also gives estimates of time to ponding (Tp).

The specific objectives of the study were:

1. To test the relationship between runoff from rainfall simulation experiments and predicted runoff using measurements of K_{fs}, ϕ_m and Tp from the GPI.
2. To examine the temporal changes in hydraulic properties measured with the GPI under two tillage systems and compare them to temporal changes in runoff from simulated rainfall.
3. To examine the effects of different cropping/tillage systems on changes in surface hydraulic properties.

Measurements with the GPI were taken on five different Tillage-2000 sites and at the Elora Research Station. At each site, paired benchmarks were selected to represent the major soil and topographic regions in the field. The GPI was used to obtain measurements of K_{fs} and ϕ_m on each of the tillage/soil landscape combinations. Undisturbed soil cores were taken to determine bulk density, saturated hydraulic conductivity (Ksat), moisture retention curves and an estimate of macro-porosity.

Rainfall simulations were conducted at three of the T2000 sites under a separate contract with the Ontario Ministry of the Environment. At one of the sites the rainfall simulations were conducted on three separate occasions in the year. The measurements of runoff, infiltration and soil loss rates from the rainfall simulations were used to verify and add to the results obtained with the GPI.

The measurements of soil hydraulic properties obtained with the GPI were highly variable, but compared favourably with those obtained through rainfall simulations. Detailed measurements from the GPI, the rainfall simulator and the soil cores showed that the long term (9 years) no-till soils at the site in Huron County had higher bulk density, lower total porosity, lower macro-porosity, lower Ksat, lower K_{fs}, lower ϕ_m, shorter times to ponding and runoff and lower infiltration rates than soils that were moldboard plowed. Similar effects of no-till were observed at another site in comparison with minimum tillage soils. No significant differences between no-till and other tillage systems were found at the remaining sites.

The results of the study indicate that there is a risk of increased surface runoff from no-till fields. However, the soil erosion losses due to the increased runoff may be offset by the increased surface protection and hence decreased particle detachment from no-till soils. No-till management systems may increase the losses of soluble phosphorus and other non-adsorbed chemicals in the runoff. There was no indication from this study that no-till increases the risk of movement of chemicals to the groundwater.

E.6.3 Effects of Tillage on the Quality of Surface Runoff and Subsurface Drainage Water; Uplands

(SWEEP Report No. 37)

The quality and quantity of water moving to tile drains and as overland runoff under no-till and fall moldboard plow tillage systems were examined in this study. The research was conducted at a Tillage-2000 site in Huron County with a sandy loam soil. A field scale comparison between no-till and fall moldboard plow tillage systems has been ongoing at this site for nine years. Management data for the site is well documented, and average annual erosion rates have been estimated by intensive Cesium-137 sampling.

A meteorological station was set up to record rainfall, temperature, windspeed, humidity, and solar radiation. Weatherproof facilities were installed for monitoring flow through the drainage tiles. ISCO® water samplers were set up to sample the tile water at 6 hour intervals during the fall-spring period and 12 hour intervals during the summer. Surface runoff was monitored by installing runoff collection flumes on selected soil landscape positions within the study field. Unfortunately, no surface runoff was recorded during the 1989 season, and the surface runoff monitoring was discontinued. Rainfall simulations, financed under a separate MOE contract, were conducted a selected soil landscape positions within the no-till and fall moldboard plow treatments. A wide range of physical and hydrological properties were measured at the site, including porosity, bulk density, texture, horizonation, and hydraulic conductivity at various depths.

A tracer experiment was conducted to examine the effects of the tillage systems on the solute transport properties of the soils. After thoroughly wetting a 1 x 7 m transect plot, a solution of KCl was evenly applied to the surface. Water samples were taken from two depths in the plot, and analyzed for chloride content. Unfortunately, this experiment produced results not representative of the true water and solute movements, since the amount of water applied interfered with the water and solute flux. A new tracer experiment design compensating for this problem was used in 1990, in addition to laboratory analysis of soil columns.

No significant tile flow was recorded until late in 1989. A total of 121 cm of precipitation was recorded between Oct. 1, 1989 and Oct. 1, 1990, which resulted in a total tile flow of 19 cm. There were no significant differences in the amount of tile flow from the two tillage treatments. It was estimated that movement of water below the tile line accounted for 49 cm out of the 121 cm precipitation.

Phosphorus concentrations in the drainage water were consistently less than a hundredth of a milligram per litre over all samples, suggesting that the transport of phosphorus away from the root zone is negligible under no-till and fall moldboard tillage treatments on a sandy loam soil. The average nitrate (NO_3-N) concentration was significantly higher in the tile water from the no-till treatment compared to the moldboard treatment in the early spring and fall periods, while the reverse was true in the late fall. Overall, the average concentration of NO_3-N in the tile water from both treatments was 10.7 mg/L, which exceeded the drinking water quality limit of 10 mg/L.

Analysis from the tracer chloride transport studies showed more macropore transport in the moldboard plow system that the no-till system. The solute transport velocity was faster in the no-till, which was attributed to increased occurrence of blocked pore domains. Total nitrogen leaching from the 1989 corn crop was estimated at 80 and 50 kg N/ha for the no-till and conventional till systems respectively. The greater amount of N leaching from the no-till was attributed to a higher N soil test in the no-till system and a requirement for less N fertilizer than the moldboard system. The same amount of N fertilizer (160 kg N/ha) was applied to both treatments.

From the results of the study, it was concluded that the no-till system should not increase the risk of chemical contamination of the groundwater. In addition, the use of the nitrogen soil test to determine fertilizer requirements would significantly reduce the occurrence of over-application of N fertilizer.

Surface water runoff at this site due to natural rainfall was negligible from both the no-till and moldboard plow treatments, due to the very high infiltration rates of the sandy loam soil. The rainfall simulations indicated that very large rainfall events would likely generate more surface runoff from the no-till system than the conventional. However, total phosphorus loss would be 2 to 4 times lower from the no-till system than the conventional. Some rainfall simulations were also conducted on a clay loam part of the field. Ortho-phosphorus losses were significantly greater in the runoff from the no-till treatment than from the conventional. Runoff volumes were also greater from the no-till treatment. Thus, it was concluded that no-till systems on heavier textured soils may result in increased runoff and phosphorus losses.

E.6.4 Effects of Tillage on the Quality of Surface Runoff and Subsurface Drainage Water; Lowlands

(SWEEP Report No. 60)

This study examined soil, nutrient and herbicide losses from a poorly drained, Brookston clay loam soil under three different tillage systems. The tillage systems included a conventional treatment (fall moldboard plow, spring disk and mid season cultivation) and two conservation tillage treatments: zero-till (direct planting in previous crop residue) and ridge-till (planting in 15 to 20 cm high ridges, reformed in midseason). The plots were located in Essex County, and were cropped in continuous corn. A limited amount of data were also obtained from a continuous sod (Kentucky Bluegrass) treatment.

Data were collected in 1988, 1989 and the first nine months of the 1990 field season. Data collection at the site included precipitation, surface runoff volume and tile flow volume, along with surface residue cover at several times of the year and grain corn yield. Surface runoff and tile flow samples were collected during runoff events. The samples were analyzed for sediment content, total sediment phosphorus, total soluble phosphorus and orthophosphates. The runoff water and the sediment were also measured for herbicide concentrations, specifically, atrazine, des-ethyl atrazine and metolachlor. An error in the analytical procedure invalidated the total soluble and sediment phosphorus results for the 1988 and 1989 samples.

A wide range of climatic conditions from dry to wet growing seasons occurred over the three years study period. As a result, runoff, soil loss, nutrient and herbicide transport and grain yield were highly variable from year to year.

Over the three years of the study, total annual sediment losses from the three tillage treatments averaged 897, 530 and 391 kg/ha for the conventional, ridge-till and zero-till systems respectively. Surface runoff accounted for a greater proportion of the sediment losses for the conservation tillage treatments, while more sediment was lost through the tile drainage system of the conventional treatment. Sediment losses from the sod treatment were only available for the first nine months of 1990, and averaged 129 kg/ha. Tile drain flow accounted for over 90% of the sediment losses from the sod treatment, as compared to 42 to 68% from the corn treatments.

For the corn treatments, fertilizer (132 kg/ha 8-32-16) was side dressed at planting. A spreader was used to apply fertilizer on the sod treatment in the spring and fall (132 kg/ha 8-32-16 both times). Average annual orthophosphate losses over the three year study period were 555, 965 and 1519 g/ha from the conventional, ridge-till and zero-till systems respectively. Most of the orthophosphate losses occurred through tile discharge. The sediment and phosphorus losses from the first nine months of 1990 are shown in Table 2.

The proportionately higher losses of phosphorus from the conservation tillage systems prompted the researchers to recommend modifications to current farming practices on flat, poorly drained, clay loam soils in order to achieve phosphorus loss reductions. One suggestion was to grow crops that have a low fertility requirement and hence

Table 2. Losses of sediment and various phosphorus forms from three tillage practices and a sod treatment (Jan.1 to Sept.30, 1990)

Treatment	Sediment (kg/ha)	Ortho-phosphate (g/ha)	Soluble P (g/ha)	Sediment P (g/ha)	Organic P (g/ha)	Total P* (g/ha)
Ridge-Till	429	1178	2485	199	1307	2684
Zero-Till	353	1701	2125	266	423	2391
Conventional	472	587	1046	197	458	1242
Sod	129	2380	4995	126	2614	5121

* 18,400 g/ha P applied to ridge, zero and conventional tillage; 36,800 g/ha P applied to sod
Total P = Soluble P + Sediment P

require less phosphorus fertilizer. Another possibility is to reduce sediment and phosphorus losses by controlling the outflow from the drainage system. This may permit more efficient use of nutrients by the crop.

Runoff events occurring soon after herbicide applications resulted in the largest amounts of herbicide transport. Herbicide concentration was higher in surface runoff water than in the tile flow, and the average concentrations were higher in the runoff from the conservation tillage systems.

Concentrations of metolachlor in the runoff were higher than for atrazine immediately after applications. However, the longer soil persistence of atrazine resulted in higher overall losses of atrazine than metolachlor. Average three year transport quantities for triazine (atrazine + des-ethyl atrazine) were 58, 23 and 62 g/ha from the ridge-till, zero-till and conventional systems respectively. Metolachlor losses averaged 46, 48 and 53 g/ha from the ridge-till, zero-till and conventional systems respectively.

The herbicides persisted longer in the soil of the conventional tillage treatment than the conservation treatments. Overall, tillage and crop residue did not significantly influence herbicide transport in surface and subsurface runoff from any of the treatments. The researchers recommended band application of herbicides over the seed row or adopting post emergence weed control strategies with low persistence herbicides as possible ways to reduce the transport of herbicides from the field into runoff water.

E.6.5 LAND RESHAPING OF LOWLAND CLAY SOILS

(SWEEP REPORTS NO. 49A AND 49B)

Land reshaping, or land planing, is the practice of smoothing out the topography of a field by making cuts and fills according to a predetermined plan to improve surface drainage. Previous studies in the United States had shown economic advantages due to land planing, but had not investigated the environmental effects. A three year study was initiated in 1988 to observe the effects of land planing relative to unplaned land. The study focused on the effects of land planing on the amount and quality of surface runoff and on crop yield.

Land planing can result in improved surface drainage on lowland clay soils through more uniform runoff. Better drained fields may facilitate timely planting and harvesting operations, and can improve plant maturation. In addition, land reshaping can reduce the possibility of yield losses due to flooding of low spots.

The objectives of the project were as follows:

1. to develop a method for measuring or estimating the phosphorus movement rates from cropped fields under planed and unplaned field conditions.
2. to locate suitable sites for the testing of the water management practices;
3. to monitor the phosphorus movement, crop yields and management requirements of the fields under the two management systems; and
4. to determine the effect of land planing on phosphorus loadings to surface water.

Farmers at three sites in Essex County and one in Kent County where land planing had recently been completed agreed to participate in the research. The four farmer co-

operators kept records of field and crop conditions, farm operations, inputs and yields.

The planed and the unplaned fields at each site were laser surveyed, and contour maps were developed, to define the boundaries of the watersheds. All four sites had subsurface tile drainage. Berms and, in some cases, sheet metal boundaries were constructed to prevent movement of water between adjacent fields.

The study also involved a modelling component. Data from each of the fields was used to prepare input data files for the CREAMS model, which can be used to make runoff, soil and nutrient loss predictions.

The soils in each of the fields were analyzed for percentage organic matter, fertility, and pH. The cropping management factor (C-value) of the universal soil loss equation (USLE) was calculated based upon records of tillage practices and percentage crop cover. Soil compaction ratings were assigned for each field.

Rain gauges were set up at three of the four sites for the duration of the study. It was thought that the proximity to Harrow (about 4 km) would allow the use of precipitation data from the Harrow Research Station for one of the sites. However, intense and spatially variable precipitation in the first two years of the study prompted the researchers to install a rain gauge at this site in the final year of the study.

V-notch weirs with stillwells and Richard's® type water level recorders were set up at the drainage outlet of the planed and unplaned fields. Six ISCO® brand samplers were installed in March of 1990 to provide hourly samples of runoff during storm events. Runoff samples were analyzed for dissolved reactive phosphorus, total phosphorus and sediment content.

Over the two year period, soil samples revealed no notable changes in nutrient or phosphorus levels between planed and unplaned fields. The land planing process did not remove all of the topsoil from any location, nor did it result in higher soil compaction ratings.

Several problems were encountered in the three year monitoring period, including equipment failure, backed up ditches, weir washouts and overflows and freezing stillwells during the winter. As a result, the data from the four monitored sites contained many gaps due to missed storm events. Thus, the flow data obtained from the monitoring could be used for detecting trends but did not provide an accurate record of the rainfall-runoff response of the planed and unplaned fields during the three year study period.

One of the sites produced very little useable data, due to frequent weir washouts and equipment failure. At two of the three well documented sites, greater amounts of runoff were recorded from the planed fields than from the unplaned fields. At one of the sites the difference was significant. Contrasting results between sites were attributed to differences in natural drainage patterns and in the size of the drainage basins. Water detention in the natural surface depressions in the unplaned fields may have contributed to the decrease in runoff.

The erosion characteristics of the planed and unplaned fields with regard to sediment and phosphorus losses through surface runoff were inconsistent, and could not be clearly defined. No consistent trends were observed, other than that sediment and phosphorus losses increased with increasing runoff volume. This trend is to be expected, since the management systems on the planed and unplaned fields were identical. The interaction of total phosphorus, dissolved reactive phosphorus and sediment losses was affected by many factors other than land planing, including rainfall intensity, extent of soil cracking, antecedent moisture and residue cover.

There were no significant differences in the yields from the planed versus the unplaned fields. However, the farmer cooperators reported that the planed fields could be worked earlier in the spring due to more rapid drying, that water ponding on the planed fields was eliminated and that a more uniform soil moisture in the planed fields provided a more uniform crop growth. These benefits were not economically significant during the three year life of the study. Thus, the estimated cost of $260/ha to $790/ha for land planing could only be justified for a high value crop such as tomatoes.

The modelling component of the study focused primarily on predicting whether or not a given set of conditions (rainfall amount, soil moisture, soil cover, etc.) would result in a runoff event. Extensive cracking of the soils at some of the sites caused wide discrepancies in the amount of rainfall required to produce runoff. The CREAMS model was modified to provide continuous updating of the soil moisture status, and to account for the seasonal nature of soil cracking. However, the modelling study stopped short of providing an accurate estimate of runoff volume and phosphorus losses from the planed and unplaned fields.

E.7 PROBLEM UNDERSTANDING

E.7.1 STRUCTURAL DEGRADATION - PILOT STUDY

(SWEEP REPORT NO. 4)

A survey investigating the structural degradation of the flat, fine textured soils of Southwestern Ontario was one of the initial projects undertaken by TED. Subsoil compaction below the plow layer, at a depth of 15-30 cm, was suspected of contributing to declining agricultural productivity, increased surface runoff and high phosphorus concentrations in runoff. The survey examined the magnitude and extent of the compaction problem on clay and clay loam soils in the study area and the resulting impact on phosphorus delivery and crop yield.

Fifty fields, from 25 farms in Elgin, Essex, Kent, Lambton and Middlesex counties, were included in the survey. Severity of compaction was evaluated using several approaches. Visual assessment considered factors such as: layering, soil structure deformation, rooting patterns, relative earthworm abundance, number and continuity of pores, strength of peds, clarity and orientation of planar voids, observed differences in these characteristics between horizons, and apparent consistency of these observations from place to place within the field. Cone and hand penetrometers were also used to evaluate compaction in the field. In addition, soil samples were collected for measurement of bulk density, texture, organic matter, fertility and moisture content.

Interviews with participating farmers provided detailed information about their field histories and agronomic management practices. Soil compaction measurements were statistically compared to management practices to identify significant linkages. A review of scientific literature was conducted to assess the problem of subsoil compaction, and to evaluate predictive models and corrective techniques for compaction.

Soil compaction was found to be a serious problem. Severe compaction problems were found mainly in Kent and Essex counties. The degree of compaction was greatest where silage corn and tomato crops were grown, and least where forage crops were grown.

Based on the extent of compaction and areal extrapolations with the Universal Soil Loss Equation (USLE), it was estimated that the effects of compaction (greater runoff) could be responsible for 10-15% of the phosphorus entering the Great Lakes from agricultural land.

Subsoil compaction was linked to yield reductions and several other negative impacts to farmers, including:

- additional energy costs to perform field operations on compacted versus non-compacted soils (estimated at $12-25/hectare/year);
- costs to ameliorate compaction by mechanical (e.g. subsoiling) or biological (e.g. forage production) methods; and,
- reduced flexibility in cropping due to wet fields and ineffective tile drainage.

The factors most strongly related to subsoil compaction were tractor size (measured by its horsepower), number of passes made over the field (especially on wet soils), and types of crops grown.

Chisel plowing was effective for ameliorating compaction immediately below the plow layer, while subsoiling was recommended when compacted layers occurred at greater depths. Benefits of chiselling or subsoiling could be long lasting if management practices were adopted to reduce subsequent compaction on the field. Examples of such practices include: reduced vehicle weights, avoiding traffic on wet fields, reduced number of passes over the field and using cropping systems that maintain the soil organic matter.

The study recognized the difficulty of isolating factors that promote compaction. The CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) model was identified as the best model currently available for predicting the effect of compaction on erosion and nutrient losses. An integrated soil compaction model that would enable a farmer to estimate effects of different cropping practices, machinery, tire sizes and soil moistures at the time of field operations on resulting soil compaction.

The researchers recommended further research on the relationship between crop yield and soil compaction, and techniques to ameliorate compaction, such as subsoiling and crop rotations. These recommendations were addressed in several subsequent TED research projects.

Other recommendations from the compaction study included:

- guidelines for visual and hand assessment of soil moisture conditions to help farmers decide when and when not to operate on their fields
- definition of critical loading weights which cause compaction under various moisture conditions
- research into the use of different tires (radials, duals, flotation tires) to reduce compaction.

E.7.2 Effects of the Use of Anhydrous Ammonia on Soil Properties and Relevance to Soil and Water Quality

(SWEEP Report No. 17)

Anhydrous ammonia is known to affect the solubilization of organic matter, to increase soil pH at the point of injection in the soil, and to serve as a soil fumigant. These effects are deleterious to soil surface structure. The objective of the study was to assess the implications of the use of anhydrous ammonia on soil properties which impact soil erosion and the objectives of SWEEP. The study was carried out in the laboratory using columns consisting of 3 soil types. Specific soil properties examined were soil structural stability and water soluble carbon; soil microbial activity; nutrient availability; and soil pH.

The 5 cm inside diameter pvc columns used in the study simulated impacts of anhydrous ammonia on the soil at the point of injection. Ammonium hydroxide, a liquid, was used as the source of ammonium in these experiments.

A large amount of nitrogen was lost using this experimental setup of 15 cm length columns with the point of injection at 0.5 cm from the soil surface. In the ammonia retention zone the following observations were made:

1. Wet aggregate stability was initially decreased at high ammonium concentrations, but was regained or increased once microbial activity resumed.

Initial loss of (wet) aggregate stability due to the anhydrous ammonia application resulted from a breakdown of macroaggregates by detachment of microaggregates, and involved dispersion of clay in the Brookston clay and Honeywood loam but not in the Gobles loam. The different responses of the soils was not explainable. Subsequent increases in aggregate stability 112 days after the a.a. application corresponded with decreases in water soluble organic carbon, which was likely due to assimilation and dissimilation by soil microorganisms. In the Brookston clay aggregate stability continued to decline over the 112 day observation period, and corresponded with increases in water soluble carbon levels in the soil of 200 to 400 mg kg^{-1}. Under field conditions aggregate stability may not be regained if soluble carbon is leached from the ammonia retention zone. If aggregate stability is not regained, soil hydraulic conductivity would decrease, and the dispersion of clay would cause a decrease in soil porosity and an increase in soil strength. Such conditions may increase the potential for soil erosion and P losses by runoff. The ammonia retention zone includes approximately 20% of the plow layer of soil, hence it is expected to take several years to produce the effect described. The experimental results suggest that losses of aggregate stability are regained.

2. microbial activity is inhibited at high ammonium concentrations but is associated with decreases in water soluble organic carbon after activity resumes.

Nitrification was the main mechanism for decreasing ammonium and pH in the retention zone, but the process was also inhibited by high pH and ammonium concentrations. Nitrifying capacity seemed to be a key factor in determining how quickly microbial activity, and consequently aggregate stability, is regained after application of anhydrous ammonia.

3. Significant long term changes in levels of available nutrients (P, K, Ca, Mg) seem unlikely to occur in the anhydrous ammonia band, except possibly a decrease for K when K-fixing clay minerals are present.

There was some increase in available P levels in the Brookston clay, attributed to the increase in soil pH to above 8.5, causing the solubilization of organic C, and thus exposing more adsorbed P on mineral surfaces. This minor effect would be expected to disappear once organic matter is redeposited on the mineral surfaces by microbial activity. Concentrations of exchangeable K seemed to be decreased by addition of ammonium hydroxide to the Gobles and Honeywood soils. High concentrations of ammonium may have collapsed 2:1 minerals (mainly vermiculite) resulting in fixation of K between clay sheets. Exchangeable Ca and Mg decreased, suggesting a negative effect of ammonium hydroxide on Ca and Mg availability. The effects were small and significant decreases in available Ca and Mg would not be expected.

E.7.3 Phosphorus Movement in Soil as a Function of Phosphorus Solubility and Reactivity

(SWEEP Report No. 53)

Laboratory and greenhouse experiments were carried out to investigate the possible role of crop residues in the release of soil phosphorus. With the consequences of reduced and zero tillage practices, crop residues are left on the soil surface and decompose more slowly. The decomposition products, organic acids were hypothesized to have an impact on phosphorus adsorption in the soil, and hence the amount of phosphorus in the soil solution. This study examined the effects of crop residues on soil phosphorus and plant nutrition.

Experiment 1

Corn residues were added to soil at 3 pH levels - 5.3, 6.4, and 7.5. Residues were either incorporated or left on the soil surface in pots in a greenhouse. A no-residue treatment served as a control. Barley was grown and harvested at Feekes's stages 3 and 6.

Differences in barley yield were evident at the second sampling date; yields were lower in the control than in the two residue treatments at the two lower pH values while there were no differences at pH 7.5. The yield increase could not be attributed to increased phosphorus levels in barley. The increased plant weights at the later harvest date was due to an increased tissue nitrogen content.

The increased yields related to increased soluble carbon contents in the soil solutions. It is possible that the decomposition of the residues released soluble nitrogen, potassium, and phosphorus. There was some evidence that soluble phosphorus levels in the soil solution increased but these increases were not significant.

Experiment 2

Soils with three different pH values were incubated with incorporated corn or alfalfa residue. Incubation with either residue type led to an increase in soluble organic C, soluble total P, and ortho-phosphate. The maximum amounts of each occurred after two to three weeks, with the total release time greater for alfalfa than for corn. It was not clear whether the increased phosphorus was due to the release of mineral-bound phosphorus or an increase in organic phosphorus. A procedure was developed to determine inorganic and organic forms of soluble P and appears as an appendix to the study report.

Experiment 3

Soils were shaken with phosphate in the presence and absence of some naturally occurring organic acids. Retention of phosphorus was less in the presence of these acids and those organic acids that form strong bonds with surfaces of soil particles were the most effective in reducing specific adsorption of phosphate. Crop residues might be expected to affect release of soil bound phosphorus by increasing the concentration of released organic acids.

E.7.4 Survey of Moisture Distribution Between Tile Drainage Laterals

(SWEEP Report No. 34)

The primary purpose of this study was to assess the effect of soil moisture content on soil compaction and crop rooting depth in the lowland clay soils of southwestern Ontario. The studies took place in 1989 and 1990 at three tile drained farms on flat, poorly drained Brookston clay soil in northern Essex County. The focus of the study was on investigating soil moisture distribution between drainage laterals and its relationship to compaction, root growth, crop development and yields. The survey type study was carried out under uncontrolled conditions in order not to interfere with the cropping program and schedule of the three farmer cooperators.

The main crop at all three sites was soybeans in 1989. One of the sites had previously been cropped with tomatoes, which often cause field compaction due to the heavy harvesting machinery. The tile drain spacing ranged from approximately 6.6 m at one farm up to 20 m at another.

At each site, two survey lines were laid out across three adjacent tile drainage laterals. Soil moisture content and bulk density measurements were made with a nuclear moisture density meter at two depths (100 mm and 200 mm) along both survey lines at each farm. Readings were taken at 3.3 m intervals. In addition, bulk soil samples were taken by hand along the survey lines for Proctor density determinations.

Ten piezometers were installed to a depth of 0.8 to 0.9 m at each site in 1989. In 1990, four piezometers and four tensiometers were installed at one site along a different survey line, to obtain additional data. Hydraulic conductivity was measured at one of the sites in 1989 and at another site in 1990, using the Guelph Permeameter. At each site the researchers made measurements and assessments of soil cracking, root development, and crop condition, growth and yield.

In addition to the field measurements, soil samples were taken to the lab for measurements of moisture content, Atterberg limits, bulk density, specific gravity and Proctor Density. Some of these measurements were made to verify the field measurements, while others were taken to gain a greater understanding of the response of the soil to compaction.

No significant difference in soil density or moisture was observed between the above tile and mid-tile locations along the survey lines. However, the highest average density was measured on the farm with the widest tile spacing. In addition, mean dry densities at the farm with tomatoes in the rotation (and the narrowest tile spacing) were lower than at the other farms, suggesting that the previous year's tomato harvest had been conducted under relatively dry soil conditions (which is likely, given that 1988 was a drought year).

The best crop yields were recorded at the site with the narrowest tile spacing, while the poorest yields were recorded at the site with the widest tile spacing. Since the 1989 growing season was relatively wet, the narrow drain spacing could have resulted in more favourable soil conditions for plant growth. It was acknowledged that many other factors besides tile spacing contributed to the yield differences, including the soybean variety, planting date, management and cultivation practices and different rainfall amounts at each site.

The results from the study suggest that the greatest amount of compaction in a Brookston clay soil will occur at soil moisture contents of about 20%, and that field operations should be avoided at or near this moisture content. Soil moisture contents at harvest time were generally less than 20%, indicating that harvesting operations should only result in compaction in wet years.

Extensive soil cracking was observed at all of the sites during the summer months. Summer rains of 25 mm were frequently insufficient to raise water levels above the level of the tile drains. The soil cracks result in rapid and deep drainage of surface runoff, possibly before the upper soil profile has been thoroughly wetted. Soil nutrients and pesticides may also be rapidly transported to the tile system or deeper by these soil cracks.

The researchers were not able to draw definitive conclusions about the moisture distribution between tile drainage laterals, due to the limitations of the survey type study.

E.7.5 Soil Loss by Tillage Erosion

(SWEEP Report No. 55)

The problem of severe shoulder slope erosion was identified in a background paper on soil erosion prepared by the Centre for Soil and Water Conservation at the beginning of the SWEEP Program. Shoulder slope erosion was considered to be the major issue to be dealt with in relation to soil erosion and crop productivity. The processes causing the erosion were not understood and the effectiveness of various control measures had only been studied for mid-slope erosion.

One of the initial research projects funded by TED (SWEEP Report Numbers 38, 45 and 46) investigated the

relationship between crop yield response to landscape variability, different tillage systems, and soil properties. It was hoped that this understanding would lead to the development of strategies for managing the variable topography of farm fields. Since the existence of severely eroded areas of the field could not be ignored in management strategies, one of the objectives of the study was to determine the processes responsible for the erosion on shoulder slopes.

The implications of the initial shoulder slope erosion study were that:

1. the rate at which tillage erosion will occur depends upon the scale and degree of complexity of the topography, thus soil loss caused by tillage erosion is not restricted to shoulder slope landscape positions, but occurred to some degree on all convex slope positions in all regions with complex topography;
2. the validity of using organic matter content resident ^{137}Cs radioactivity concentration as indicators of soil redistribution within the landscape is questionable, since soil translocation by tillage can result in changes in the concentration of soil elements at a point in the landscape without changes in the quantity of soil;
3. that predictive soil loss and crop productivity models that do not include the process of tillage erosion do not represent reality on cultivated agricultural land in complex topography; and
4. soil conservation measures that do not include the reduction of tillage erosion will not be effective in controlling soil loss on upper slope landscape positions of cultivated agricultural land.

The researchers concluded that differential upslope - downslope soil loss by tillage explained most of the soil loss observed on shoulder slope positions. Tillage erosion is the process of soil loss that results from the translocation of soil by tillage operations. Tillage erosion results in a loss of productivity on shoulder slopes due to the loss of topsoil. It also reduces productivity on lower slopes because after the topsoil is totally eroded, the subsoil begins to erode and moves down to cover the topsoil on the lower slope positions. It is important, therefore, that this erosion be managed. In order to do that it must be understood.

The tillage erosion study was initiated in order to explore in greater detail the results and implications of the shoulder erosion study. The objectives of the tillage erosion study were:

1. To determine the effect of tillage implement type on the extent of soil translocation by tillage.
2. To determine the effect of slope gradient and landform on the extent of soil translocation by tillage.
3. To determine the effect of direction of tillage in relation to slope and up and down slope tillage directions on the extent of soil translocation by tillage.

Four tillage treatments were tested over two field seasons at two topographically complex, but similar, field sites in Huron County. Paired plots at one field were used to compare soil translocation by upslope and downslope tillage over a range of slope gradients with a moldboard plow and with a chisel plow. At another field, similar experiments on paired plots compared tillage translocation with a tandem disk and a C-tine cultivator.

The soil texture of both field sites was sandy loam. Soil translocation was measured using the tracer-pulse method. Chloride was utilized as the labelling element to generate the tracer pulse. Soil translocation was calculated using the synthetic step response distribution synthesized from a succession of convoluted Cl pulse response distributions. Soil loss caused by tillage erosion was measured as the net downslope soil translocation by tillage.

Measurements of soil translocation, net downslope translocation and soil loss for all four tillage implements and for treatments of tillage implements were highly variable. As a result, that soil loss and accumulation were observed throughout the topography, regardless of slope position. Although this variability existed, net soil losses were observed on the upper slope landscape positions for all four tillage implements, indicating that each tillage implement moved more soil downslope than upslope. The chisel plow, moldboard plow, tandem disc and cultivator all caused tillage erosion which resulted in soil loss.

Soil losses resulting from two passes, one upslope and the second downslope, of the chisel plow, moldboard plow, tandem disc and cultivator, when averaged over the linear and convex upper slope landscape positions, were 0.19 kg m^{-2}, 0.05 kg m^{-2}, 0.43 kg m^{-2}, and 0.54 kg m^{-2}, respectively. Assuming an equal number of upslope and downslope passes for each tillage operation, the average soil losses per tillage pass for the chisel plow, moldboard plow, tandem disc and cultivator were estimated to be 0.09 kg m^{-2} (0.9 t ha^{-1}), 0.03 kg m^{-2} (0.3 t ha^{-1}), 0.22 kg m^{-2} (2.2 t ha^{-1}), and 0.27 kg m^{-2} (2.7 t ha^{-1}), respectively.

The researchers also looked at maximum soil losses per tillage pass, maximum absolute values of net downslope soil translocation and at the range between the minimum and maximum values of soil translocation for each tillage implement. When the different relationships were examined no single tillage implement consistently resulted in more tillage translocation.

While all four tillage implements were considered erosive, the relative erosivity of the four implements could not be assessed conclusively because of the variability in the data. The observed values of soil loss were relatively small, but exceeded acceptable limits.

The results indicated that there are relationships between soil translocation and slope gradient, tillage depth and tillage ground speed, however, these relationships are not always strong nor are they consistent between tillage implements, or within tillage treatments of tillage implements. There was some indication that soil translocation increased as slope gradient, tillage ground speed, and tillage depth increased. There was also some indication that ground speed increased as slope gradient increased, that ground speed decreased as tillage depth increased, and that tillage depth increased as slope gradient increased.

The inconsistency in the relationships suggested that there are other factors involved in the translocation of soil by tillage other than slope gradient, tillage depth and tillage ground speed. The shape and arrangement of tillage tools, and the responsiveness of tillage operator, as well as slope gradient, tillage depth and tillage ground speed, could also have affected soil translocation.

In order to reduce tillage erosion losses on upper slope landscape positions, it was recommended that farmers reduce the frequency and intensity (depth) of their tillage operations, and used shorter and narrower tillage implements (less scalping will occur on uneven topography). Where possible, tillage patterns within fields should be varied so that the same area is not subjected to downslope tillage year after year. All four tillage implements were found to be erosive, but it could not be concluded which of the above recommendations would provide the greatest reductions in soil loss resulting from tillage erosion.

Recommendations for further research were:

1. develop a practical and accurate method of measuring tillage depth for both primary and secondary tillage operations;
2. conduct more rigorous studies of the effects of slope gradient and curvature, tillage depth, and tillage ground speed on soil translocation and tillage erosion;
3. examine the role of tillage tool shape and arrangement, tillage operator, and tractor-implement match on soil translocation and tillage erosion; and
4. examine soil translocation and tillage erosion under a broad range of soil conditions to determine the effects of soil texture and soil moisture content on soil translocation.

Research on tillage erosion is continuing, with funding from the National Soil Conservation Program. The focus of the research is on the development of a new soil loss prediction model which includes tillage erosion.

E.7.6 The Response of Soil Microflora and Fauna to Spring Plowing of Zerotill and Pasture Soils

(SWEEP Report No. 30; Progress Bulletin Issue 11)

The study described the relative stability of pasture and cropped land and tested the assumption that agroecosystems are unstable because they are less diverse. Stability allows the soil community to recover from environmental or human induced perturbations helping to maintain the community structure. When community structure recovers, pest management and decomposition can proceed uninhibited.

The trial was located on a well drained Harriston loam. The agricultural field had been in zero tillage for five years with a corn-corn-barley-wheat(red clover) rotation. In the year of this study the field was planted with winter wheat which was underseeded with red clover. Various parameters were examined following perturbation, by plowing, of each of a long term pasture and zero tillage

system. Soil microflora and fauna populations were monitored in addition to soil microbial biomass nitrogen and phosphorus, infiltration, soil bulk density and hydraulic conductivity. Plant residue decomposition rate was estimated at the soil surface and at a soil depth of 10 centimetres. These rates of decomposition in conjunction with the estimates of soil microflora and fauna populations were used to explain differences in the decomposition of residues at the surface of the soil relative to those that were buried.

The soil microflora include the fungi and bacteria. They dominate the soil in their numbers and the biomass they comprise. These microflora convert complex organic compounds into simpler ones.

The microfauna and mesofauna include nematodes, mites, and other small soil invertebrates. They comprise a group with variable feeding habits. These include feeding on microflora, plant tissue, and other soil animals. They are also responsible for some tunnelling.

The macrofauna include the earthworms, millipedes, and other large invertebrates. This group is responsible for the fragmentation and redistribution of organic materials within the soil. They are responsible for the network of tunnels and channels in the soil. Also included in this group are large predators such as spiders and carabid beetles.

FINDINGS

Earthworm numbers by the end of the season in the unplowed pasture were more than double those in the unplowed zero tillage soil. Earthworm mass was higher in pasture soils, and the masses came closer to returning to those levels of the unplowed soil at the end of the season in the zerotill soil. Earthworms did not recover from cultivation in one sampling season.

The soil microbial biomass was relatively constant over the season with a peak in June, and a decline in late July and August. Microbial biomass was almost always higher in the pasture soil than in the zero tillage soil; the plowed and unplowed soils of each system were similar throughout the season.

Saturated hydraulic conductivity and dry soil bulk density were significantly higher in the unplowed treatment of the zero tillage systems, indicating that pore continuity was higher where the soil was undisturbed. In the pasture systems, however, hydraulic conductivity was greater by a factor of 10 in the plowed soil compared with its unplowed counterpart; this result was attributed to the plowing action destroying roots which had occupied (plugged) the pores of the unplowed soil. The literature suggests that cultivated soil has more macropores than uncultivated soil, but that uncultivated soil has 2 to 9 times more bioporosity, attributed mainly to earthworms. Average infiltration rate increased with increasing earthworm number over the plowed and unplowed zero tillage and pasture systems. This indicated the importance of bioporosity in these soils.

Decomposition rate of residues, measured 39 and 69 days after plowing, was higher in the zero till plowed than in the pasture plowed. This may be explained by the faster return times of the decomposer animal populations in the zero till; that is, the microbial biomass, number of nematodes, and the number of slugs and sowbugs returned faster and all are important in decomposition processes. The author of the study suggests that is was the rapid return of the macro-invertebrates in the plowed soils rather than differences in soil microbial biomass which were likely to have caused the more rapid litter decomposition rate in the zero tillage system.

In the context of this study, stability is defined as the ability to remain at or return to ground state level after perturbation. In this study, the ground state is the animal population in the unplowed soil while the disturbed state is the animal population in plowed soil. Return times of population parameters were faster in zero till soil, without exception, and thus stability differs between pasture and zero tillage systems. The author described three conceptual models which are used to explain the greater stability of the zero tillage system compared with the pasture system.

Diversity consists of two components - richness and evenness. Richness refers to the number of different kinds of soil animals, while evenness refers to the similarity in numbers of individuals of each kind. By examining the components of diversity in zero till and pasture soils - richness and evenness - it was concluded that diversity appears to be similar or slightly greater in pasture than in the zero till system.

E.7.7 Effect of Woodlot Borders and Crop Residue on the Distribution of Invertebrates in Agroecosystems

(SWEEP Report No. 47)

A one year study was performed to determine if invertebrate abundance and diversity decreased in agricultural fields with increasing distances from woodlots and if crop residue cover in fields influences the distribution of invertebrates at increasing distance from woodlots. Cryptozoic invertebrates are important in pest control, in residue decomposition, and subsequent nutrient release. Foliage arthropods are found on crop and weed plants; some are important in predation and parasitism.

At each of two different sites treatments consisted of two residue levels. On site 1, in Mount Forest, Ontario, a previous silage corn crop served as the no residue treatment while a barley crop was used as the treatment with residue remaining on the surface. During the year of the experiment, both of these fields were harrowed lightly and corn was planted. Each field was surrounded by woodlot.

At site 2 in Fergus, Ontario, the treatments were soybeans fall chisel plowed and soybeans spring chisel plowed, allowing residue to overwinter.

All fields in the study were sampled for abundance, richness, occurrence and evenness of cryptozoic fauna. Abundance represents the number of individuals found in a particular sample. Richness represents the number of different taxa found in a particular sample. Occurrence represents the number of taxa found in all samples and evenness is the equatability of distribution of abundance amongst the taxa.

Pitfall traps were used to collect terrestrial invertebrates. Foliage arthropod traps enabled sampling of fauna on plants. An intercept trap was used to capture flying insects. Earthworms were sampled using a formalin and water solution, as well as through soil excavation.

Findings

There was a decrease in the number of cryptozoa as distance from the woodlot increased regardless of tillage or residue level (Figure 4.7-1). In summer, cryptozoic invertebrates appeared to be spread over the entire sampling area whereas in the fall, many moved back to the woodlot and there was a higher gradient in numbers between field and woodlot.

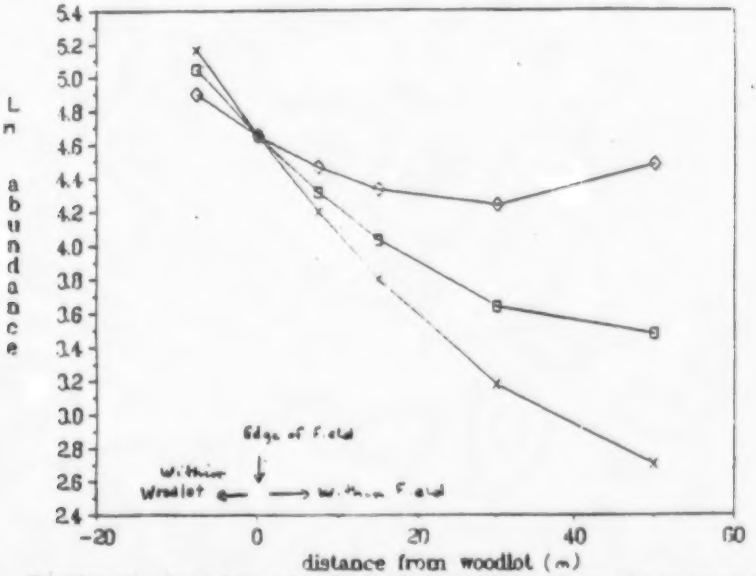


Figure E.7-1 Cryptozoic abundance in the barley residue - corn cropping system at 3 sampling periods (copied from SWEEP Report No. 47, Figure 3)

Slugs and millipedes were concentrated near the woodlot. Woodlots appeared to be important shelters for cryptozoic invertebrates. There were more invertebrates at every distance from the woodlot in the spring plowed soil, probably due to the presence of crop residue offering protection; this was evident in the soybean residue but not barley residue.

There were fewer number of taxa in a sample with increasing distance from the woodlot and this would appear to be permanent since it did not change with date. This was consistent across cropping systems, although the presence of residues increased the number of taxa in a sample at each distance out from the woodlot.

The distribution of numbers of each taxa increased with distance from the woodlot- ie. equatability of distribution was greater in the field than in the woodlot and its edge. The greater dominance in woodlots consisted largely of ants, harvestmen, slugs, and sowbugs. Crop residue promoted persistence of several dominant taxa, as evidenced in the soybean system. Intuitively, competition and specialization should be greater in the woodlot where invertebrates are present year-round. Crop residue promoted dominance as well.

Earthworm number and mass increased with increasing distance from the woodlot. The earthworm number was higher in no residue corn than in the barley residue corn, suggesting barley residue did not increase abundance of earthworms.

CONCLUSIONS

The study suggests that large fields may have taxa poor centres with several dominant taxa being present in relatively large numbers for part of the year. This may interfere with natural predator control of pests and with decomposition and nutrient cycling. It appears to suggest that smaller fields surrounded by a windbreak are more likely to take advantage of biotic processes.

E.7.8 YIELD REDUCTION EFFECTS OF CROP RESIDUES IN CONSERVATION TILLAGE - (STUDIES ON PHYTOTOXINS)

(SWEEP REPORT NO.56; PROGRESS BULLETIN ISSUE 6)

A three year study was carried out to understand the significance of phytotoxic compounds related to crop residues in conservation tillage. Farmers leaving crop residues on the soil surface were concerned that yield reductions in crops planted into residues might be related to allelopathic compounds inhibiting germination or early growth. In these studies specific volatile fatty acids (VFAs) and phenolic compounds (PCs) were tested as the allelopathic compounds and were either applied to treatments or measured in residue treatments under investigation. Several types of compounds have been determined to be allelopathic.

The study consisted of both field and laboratory components. For the most part, the field studies did not detect allelopathic chemicals and did not necessarily produce yield reduction effects of crop residues. The laboratory experiments were able to provide evidence for the presence of particular compounds and demonstrate the extent to which particular concentrations may produce deleterious effects on early plant development.

FIELD STUDIES

1. Evaluation of surface placement of overwintered corn and fresh rye plant residues for phytotoxin production

Over two field seasons corn was grown on a site in which overwintered and fresh rye residues were moved into place. Two rates of residue were used. A no residue control was used and a garden blanket served to simulate the physical effects of the residue cover.

Little evidence of VFAs or PCs was found except following a rainfall event where the quantities measured were at the low end of the detection limit of the instrumentation. The residue effects of the corn yields grown in the residues varied. Generally, the residues resulted in cooler temperatures early in the growing season which resulted in smaller, paler plants at earlier crop stages. By mid-season differences were not evident. The presence of residues benefitted the corn during drought periods. In 1988, corn residues reduced corn grain yields whereas the rye residues applied at the heavy rate enhanced yields. In 1989 rye residues enhanced final grain yields of corn.

2. Effects of various crop residues and placement on no-till corn

Corn was grown in various crop residues as described in E.2.5, Experiment 3. Residues were either left in row or removed with trashwhippers.

In both years of the study, the residues had little effect on corn emergence. Grain corn yields were higher when planted after crops other than itself, including silage corn, but differences were not significant. Phenolic compounds were detected and in 1990 they were evident late in June, indicating a possible impact on later season growth and yield. Final plant populations were not significantly different among residues or placements.

In one study year (1989) corn planted into late-killed red clover required the most number of days to emerge. In another year (1990) the greatest number of days for corn to emerge occurred where corn was following grain corn. Corn generally emerged most rapidly under rye, and early-killed rye in particular.

Corn plant weights also tended to be higher following the early-killed rye and soybeans while red clover tended to result in lower corn plant weights.

Residue removal from the row area generally increased grain corn yields in 1989 for most residue types. In 1990 both grain corn yield reductions and increases were observed when residues were removed from the row areas of particular residues.

3. Calcium nitrate as an amendment

Since $Ca(NO_3)_2$ proved effective in laboratory studies in reducing the accumulation of VFAs and PCs, an attempt was made to evaluate its effectiveness in the field. In corn grown in a fresh rye residue cover, low levels of VFAs and PCs were detected and some specific compounds were not detectable. There were some differences in grain yields due to the treatments but they were not related to the amendments to reduce phytotoxins.

LABORATORY STUDIES

1. Determining soil environmental factors controlling the production and accumulation of phytotoxins

Residues of corn stover, winter wheat straw, green rye, and soybean were incubated in soils at field capacity and saturation moisture contents and at temperatures of 4, 15 and 25°C.

Under wet and high temperature conditions, fresh, green, or easily decomposable residues were found to have the greatest potential for accumulating higher concentrations of VFAs and total phenolics. During the experiments, soils incubated under these conditions had quantities of compounds that were detectable within 48 hrs. to 28 days. The pattern was similar using weathered residues but the levels of detectable compounds were lower.

VFA production tended to increase over time, reaching a peak accumulation at 14 and 28 days of incubation. The VFAs are by-products of fermenters. Total phenolic concentrations in the soil tended to be higher, be produced earlier, and decrease over time, compared with the production of VFAs. Phenolic compounds are initially leached from residues.

2. Weathered versus fresh residues at 15°C in a saturated soil

Mature alfalfa, corn stover, and soybean straw were incubated fresh or after overwintering.

Green material had a greater potential for accumulating concentrations of compounds and it was concluded that the more decomposable materials were more phytotoxic.

3. Effects of VFAs and PCs on early corn radicle growth

Various solution concentrations of VFAs and PCs and certain combinations of compounds were examined in a bioassay using corn seeds.

The inhibition concentration of VFAs differed according to the particular acid or combination of acid compounds. Levels of inhibition ranged from 0.001 M to 0.01 M.

Only two of the phenolic acids and alone and in combination resulted in inhibition of corn radicle growth. Inhibition occurred at the lower but not the higher concentration tested.

The experiments demonstrated that VFAs and PCs are inhibitory to early corn radicle growth and that the effects of PAs were non-additive.

4. Winter wheat bioassays

Radicle growth of winter wheat was inhibited to a greater extent than coleoptile growth by the presence of VFAs. At high concentrations of VFA's (10^{-2} M), inhibition was almost complete.

In the bioassays (corn and winter wheat) not all hybrids were affected similarly.

APPENDIX F

List of TED Reports

LIST OF TED REPORTS

SWEEP Rep.No.	Title of Report	Author	Date
2	A Review of Farm Based Soil Conservation Research and Development	D. Cressman Ecologistics Ltd.	March, 1988
4	Assessment of Soil Compaction and Structural Degradation in the Lowland Clay Soils	L. Leskiw Can-Ag Enterprises	May, 1988
12	Choice and Management of Cover Crop Species and Varieties for Use in Row Crop Dominant Rotations	R. Samson C. Foulds Dr. D. Patriquin Resource Efficient Agricultural Production (REAP) - Canada	May, 1990
13	The Effect of Moldboard Shape on the Residue Management Potential of the Moldboard Plow	J. Sadler Richards Conservation Management Systems (CMS)	July, 1990
14	The Effect of Terraces on Phosphorus Movement	K. McKague Ecologistics Limited	July, 1990
16	Effects of Subsoiling on Corn Yields and Soil Conditions in Southwestern Ontario	L. Leskiw A. Laycock Can-Ag Enterprises	September, 1990
17	Effect of Ammonia on Soil Properties and Relevance to Soil and Water Quality	D. Cressman *et al.* Ecologistics Limited	October, 1990
18	Effects of Management on Soil Hydraulic Properties	B. O'Neill, M.Sc. Dr. R.G. Kachanoski Dr. D.E. Elrick University of Guelph	September, 1990
19	Studies on the Control of Problem Weed Species in Conservation Tillage Systems	Dr. B.L. Frick Southwestern Ontario Agricultural Research Corporation (SWOARC)	September, 1990
19a	Appendix 1 - 4, Studies on the Control of Problem Weed Species in Conservation Tillage Systems	Dr. B.L. Frick SWOARC	September, 1990
21	Efficiency of Residue Management for Providing Optimal Corn Growing Conditions in a Non-Tilled Sandy Loam	Dr. M.C. Fortin SWOARC	March, 1991
22	Field Emergence Predictors for Grain Corn under No-till Managements	Dr. H.J. Hope R. Maamari SWOARC	May, 1992
23	Processes Involved in Mobilization of Phosphorus in Different Farming Systems in Southwestern Ontario: Nutrient Levels in Plant Tissues and Soils	A. Abboud REAP	March 1991
24	Investigation of Soil and Crop Response to Fall Subsoiling in Southwestern Ontario	L. Leskiw A. Laycock Can-Ag Enterprises	August, 1991

SWEEP Rep.No.	Title of Report	Author	Date
25	The Development and Testing of a Dry Fertilizer Placement Machine	R. Prong D. Albin Albin-Till-Tech Joint Venture	August, 1991
26	The Use of Kelp and Molasses in an Aeration Tillage System	J. Sadler Richards CMS	July, 1991
27	Cereal Cover Crop Study	J. Sadler Richards CMS	July, 1991
28	The Effect of Split Applications of Nitrogen on Corn Yields under Ridge and No-till Conditions	B. Shillinglaw J. McGregor SWOARC	March, 1991
29	The Effect of Organic Mulches on Soil Moisture and Crop Growth	Dr. T.J. Gillespie Dr. C.J. Swanton C.S. Wagner Riddle University of Guelph	August, 1991
30	The Response of Soil Microflora and Fauna to Spring Plowing of Zero-till and Pasture Soils	P. Neave Dr. V. Thomas University of Guelph	October, 1991
31	Field Scale Tests of the Modified Moldboard Plow	J. Sadler Richards CMS	October, 1991
32	Optimal Herbicide Use in Conservation Tillage Systems	J.E. Shaw V.S. Malik Ridgetown College of Agricultural Technology (RCAT) Dr. C.J. Swanton University of Guelph	August, 1991
33	Development of a Computer-based Farm Decision Support Framework (Phase 1)	R. Hoffman Dr. B. McInnis Robbert Associates	October, 1991
34	Survey of Moisture Distribution Between Tile Drainage Laterals and its Relationship to Compaction and Rooting Depth in Flat Clay Soils	C. Mirza M. Percy Strata Engineering Corporation	December, 1991
35	Nutrient Distribution and Stratification Resulting from Conservation Farming	D. Cressman Ecologistics Limited	November, 1990
36	Red Clover Cover Crop Studies	J. Sadler Richards CMS	January, 1992
37	Effects of Tillage on the Quality and Quantity of Surface and Subsurface Drainage Water: Uplands	Dr. R.G. Kachanoski University of Guelph University of Waterloo	January, 1992
37a	Appendix I - X, Effects of Tillage on the Quality and Quantity of Surface and Subsurface Drainage Water: Uplands	Dr. R.G. Kachanoski University of Guelph	January, 1992

SWEEP Rep.No.	Title of Report	Author	Date
38	Management of Farm Field Variability, I. Quantification of Soil Loss in Complex Topography, II. Soil Erosion Processes on Shoulder Slope Landscape Positions	Dr. R.G. Kachanoski Dr. M.H. Miller D.A. Lobb Dr. R.D. Protz University of Guelph Dr. E.G. Gregorich Agriculture Canada	January 1992
39	Report on "Tye-Drill" Modifications for Sowing Soybeans on Commercial Farms Under No-Till Conditions	J. Rigby *et al.* SWOARC	January, 1992
40	Management of Mulch Tillage Systems on Clay Soils	G.A. Stewart Dr. T.J. Vyn University of Guelph	March, 1992
41	Evaluation of Row Crop Planter Modifications for Corn Production within Conservation Tillage Systems	G.A. Stewart Dr. T.J. Vyn University of Guelph	March, 1992
42	Report on Development and Operation of the Cross-Slot Planter	J. Rigby Rondeau Agricultural Conservation Corporation	March, 1992
43	The Use of Cover Crops for Nutrient Conservation	Dr. M.H. Miller Dr. E.G. Beauchamp Dr. T.J. Vyn G.A. Stewart J.D. Lauzon Dr. R. Rudra University of Guelph	March, 1992
44	Comparison of Planters and Fertilizer Application Systems for No-till Corn	Dr. M.H. Miller University of Guelph	March, 1992
45	Management of Farm Field Variability, III. Effect of Tillage Systems on Soil and Phosphorus Loss	Dr. R.G. Kachanoski Dr. M.H. Miller A.P von Bertoldi University of Guelph J.D. Aspinall Ontario Ministry of Agriculture and Food	January, 1992
46	Management of Farm Field Variability, IV. Crop Yield, Tillage System, and Soil Landform Relationships	Dr. R.G. Kachanoski Dr. M.H. Miller A.P von Bertoldi University of Guelph J.D. Aspinall Ontario Ministry of Agriculture and Food	May, 1992
47	Effect of Woodlot Borders and Crop Residue on the Distribution of Invertebrates in Agroecosystems	P. Neave Dr. V. Thomas University of Guelph	May, 1992

SWEEP Rep.No.	Title of Report	Author	Date
48	The Feasibility of Band Spray Application in Conjunction with Inter-row Cultivation in No-till Corn	J. Rigby SWOARC J.E. Shaw RCAT	May, 1992
49a	Land Reshaping of Lowland Clay Soils, I. Field Study	L. Leskiw A. Laycock Can-Ag Enterprises	May, 1992
49b	Land Reshaping of Lowland Clay Soils, II. Modelling Report	Andrew H. Marshall Can-Ag Enterprises	May, 1992
50	Evaluation of O.B.A.T.A Approach to Low Input Farming	L. Leskiw A. Laycock Can-Ag Enterprises	May, 1992
51	Loss of Nitrogen by Microbial Denitrification, Nitrification, Surface and Tile Runoff: Relation to Tillage Methods	Dr. D.J. McKenney University of Windsor Dr. C.F. Drury Agriculture Canada	May, 1992
52	Field Scale Tests of Cover Crops I and II	J. Sadler Richards CMS	May, 1992
53	Phosphorus Movement in Soil as a Function of Phosphorus Solubility and Reactivity	Dr. L.J. Evans University of Guelph	May, 1992
54	Rainfall Simulation to Evaluate Erosion Control on TED Research Sites	G. Schell Ecological Services for Planning Ltd.	July, 1992
55	Soil Loss by Tillage Erosion: The Effects of Tillage Implement, Slope Gradient, and Tillage Direction on Soil Translocation by Tillage	Dr. R.G. Kachanoski Dr. M.H. Miller D.A. Lobb University of Guelph	June, 1992
56	Yield Reduction Effects of Crop Residues in Conservation Tillage	Dr. R.P. Voroney B.J. Farquharson K.J. Janovicek Dr. E.G. Beauchamp Dr. T.J. Vyn University of Guelph Dr. M.C. Fortin Agriculture Canada	June, 1992
57a	Field Testing of Cover Crop Systems for Corn and Soybean Production	R. Samson A. Arkinstall J. Quinn REAP	June, 1992
57b	Effect of Winter Rye Mulches and Fertilizer Amendments on Nutrient and Weed Dynamics in No-Till Soybeans	R. Samson J. Ornielan REAP Dr. C.F. Drury Agriculture Canada	June, 1992

SWEEP Rep.No.	Title of Report	Author	Date
58	Manure Management in Conservation Farming	R. Samson Dr. A. Weill A. Arkinstall J. Quinn REAP	June, 1992
59	Evaluation of 58 Commercial Corn Hybrids (2850 to 3450 C.H.U.) in Two Conservation Tillage Systems and Conventional Tillage in Kent County, Southwestern Ontario	G. Scheifele RCAT J. Rigby Farmer Cooperator D. Smith Farmer Cooperator Dr. H. Hope Agriculture Canada	June, 1992
60	The Effect of Conservation Tillage Practices on the Losses of Phosphorus and Herbicides in Surface and Subsurface Drainage Waters, A. Soil Erosion, Phosphorus Loss and Corn Yield, B. Herbicide Losses	Dr. J. Gaynor D. Bissonnette SWOARC	May, 1992
60a	Appendix, The Effect of Conservation Tillage Practices on the Losses of Phosphorus and Herbicides in Surface and Subsurface Drainage Waters	Dr. J. Gaynor D. Bissonnette SWOARC	May, 1992
Not Applicable	Conservation Tillage Handbook, Equipment Modifications and Practical Tips	J. Sadler Richards CMS Ontario Ministry of Agriculture and Food	

APPENDIX G

Soil Erosion and Phosphorus in Runoff from
Agricultural Cropland in Southwestern Ontario

Soil Erosion and Phosphorus in Runoff from Agricultural Cropland in Southwestern Ontario

A review of relevant literature

prepared for

Ecological Services for Planning Ltd.

by

The Centre for Soil and Water Conservation

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June, 1987

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1. INTRODUCTION

Soil and Water Conservation has, in recent years, received increased attention in Canada's scientific, political and academic forums. Recognition of the significance of non-point sources of pollution has resulted in a renewed commitment to understand and combat problem conditions. While a wide variety of possible non-point sources exist in Ontario, PLUARG studies (PLUARG 1978) indicated that two-thirds of diffuse source phosphorus, found in Lake Erie, is directly related to agricultural activity.

The Southwestern Ontario Soil and Water Environmental Enhancement Program (SWEEP) has been developed to respond to existing and potential deterioration of soil and water resources. This co-operative Federal-Provincial initiative has as its goals 1) The reduction of phosphorus loading to Lake Erie by 200 tons per year by 1990, from non-point agricultural cropland sources and 2) the increased productivity of the primary agricultural sector in southwestern Ontario by reducing or arresting soil erosion and degradation.

Included in the SWEEP mandate is the evaluation of existing methods and development of new technologies which may be effective in addressing soil erosion and/or phosphorus loading problems. This report will attempt to facilitate this process by reviewing our current understanding of these problems as well as our ability to prescribe and implement solutions. Soil erosion and phosphorus loading will be examined with regard to physical processes, extent and distribution, perceived impacts and available remedies. In addition to documenting current knowledge and methods, informational deficiencies, which may impede the successful development of remedial measures, will be identified. It is hoped that identifying key issues and information gaps will help define research priorities and ensure that the financial and human resources of SWEEP are focused on areas of greatest need and potential. The desired end result of the research program will be the development and validation of technologies that are not only effective, but also acceptable to land managers in both their cost and complexity.

Although the soil erosion and phosphorus loading components of the program are closely related, they are examined separately in this report. The linkages and interdependencies that exist will be identified whenever appropriate. Despite the separation of possible solutions in this report it is understood that high priority must be given to technologies which are thought to be effective against both soil loss and phosphorus yield.

2. SOIL EROSION

Soil erosion has been recognized, for many years, as a problem with potentially serious economic and environmental consequences. Excessive rates of soil loss threaten both the quality of Ontario's water resources and the economic viability of many of the farming enterprises. While there is presently renewed commitment to combat soil degradation, understanding of the problem is complicated by the many physical and human processes and inter-dependencies which are at work on the landscape. The major forms of soil degradation in Ontario are erosion and compaction. The most serious of these is soil erosion.

Increased soil erosion in Ontario is generally attributed to an increase in row crop production and a reduction in cereal grain and hay crop production (Miller 1984). Traditional mixed farming has now been replaced by specialization and the frequent separation of livestock and crop production. During the decade 1974 to 1984 the number of cattle in the Province of Ontario declined by over 20% (Ontario Ministry of Agriculture and Food 1986). This has resulted in lessened demand for hay crops and thus contributed to the proliferation of row cropping.

In order to ensure that new technologies will be effective in the field, their development must be based on a thorough understanding of all aspects of the soil erosion problem. Required background includes information on the physical processes, the causes and the impacts of erosion. In addition, we must be able to determine the extent and distribution of erosion, at large or small scale, in order to apply technologies to areas of greatest need.

2.1 MEASUREMENT AND PREDICTION

To identify the existence of current or future agricultural productivity problems because of sheet or rill erosion, we must possess reliable techniques for both measurement and prediction. Measurement techniques provide detailed and reliable data on soil loss but require hands-on field level involvement. While such labour intensive methods are feasible in plot-sized examinations, their application to broadscale situations is generally thought to be cost prohibitive. Predictive methods form the basis for regional analysis of soil loss and are required for the effective allocation of remedial measures.

As noted above, direct measurement of soil erosion is possible and has occurred in Ontario and elsewhere. Techniques include the long-term monitoring of field plots, the use of simulations and the use of tracers. Despite the apparent reliability of actual field measurement, Begg (1982) notes the necessity for long-term monitoring to ensure the validity of data.

Measurement of soil loss under simulated wind and rainfall conditions has been possible for many years. Apparatus such as wind tunnels, rainfall simulators and soil erosion flumes facilitate laboratory measurements of erosion, or more specifically, erodibility. Dickinson and Pall (1982) have utilized laboratory simulation to establish the seasonal variation of erodibility on several soil types from two southern Ontario watersheds. Measured values of erodibility are used as information inputs to predictive procedures which will be discussed later.

Tracers provide an effective method of measuring soil loss and are available in many forms (Carson and Kirby 1972). One currently evolving technology is the use of ^{137}Cesium as a tracer in the measurement of soil movement. This radio-active isotope was released in the atmosphere during the 1950's and 1960's. It has subsequently been removed from the atmosphere by precipitation and deposited worldwide. Ritchie, Spraberry and McHenry (1974) have established the validity of ^{137}Cesium as a tracer and concluded that it is possible to correlate measured movement of such radioactive material with soil loss. Studies are currently underway in Southern Ontario which are using ^{137}Cesium as a soil erosion measurement technique.

A study being conducted in Brant County, by Kachanoski and co-workers from the University of Guelph, is utilizing ^{137}Cesium as a method of measuring past erosion. Core samples taken 16 years ago have recently been tested for ^{137}Cs content. The analysis of current samples taken from the same sites will provide a valuable comparison from which soil loss can be calculated. Such studies provide not only opportunities to develop a data base of measured erosion, but also provide methods of testing and validating predictive techniques.

As noted above, the development of a data base of actual measured erosion on various landforms and soils is desirable. A review of relevant literature reveals that such information is very limited in Ontario. While several studies have been conducted using various methodologies to estimate erosion and sediment problems only one has included detailed field checking of an area (Miller 1984). In-field measurement of soil loss and associated yield reduction comprised part of a 1982-1983 study conducted by Battiston and Miller (1984). This research focussed on

a 300 km^2 area in Wellington County and the Region of Waterloo and examined the extent and severity of erosion and its effect on soil productivity.

The extent of erosion was measured through the use of aerial photography and findings were validated by field checking. The examination of stereo pairs enabled researchers to identify erosional phases within fields and over larger areas. Extrapolation enabled mapping of the study area and a means by which eroded areas were expressed as a percentage of total area. It was found that 18% of agricultural cropland in the study area was moderately to severely eroded. This study concluded that remote sensing techniques provide an accurate and fast method of delineating currently eroded areas at both large and small scale. It was also noted by Battiston and Miller (1984) that severe erosion typically occurred in small areas and in close proximity to less eroded sites. Eroded areas were most often associated with upper slope positions on knolls. These findings are of particular relevance to a discussion of remedial measures presented later in this report.

From the material reviewed, it is evident that satisfactory techniques for the measurement of soil loss are in existence. The data base of measured erosion on various Ontario soils is very limited, however, and more studies, using various measurement techniques, are needed. While such studies provide insights into the extent and distribution of past erosion, the analysis of potential erosion on broadscale levels requires methods for prediction.

Predictive tools used in the examination of both the amount and extent of soil erosion are based primarily on the Universal Soil Loss Equation. This equation, developed in the United States over two decades ago, has served as the basic element of various techniques and methodologies used to assess the magnitude of erosion, to identify areas of excessive erosion and to project long-term changes in crop yield from soil erosion (Foster et al. 1985).

The Universal Soil Loss Equation (USLE) was derived from statistical analysis of 2,300 plot-years of data from natural runoff plots plus the equivalent of 1000-2000 plot-years of data from rainfall simulators. Foster et al. (1985) have summarized the development and validation of the USLE in the United States.

The USLE was designed to predict soil loss from sheet and rill erosion and calculate long term average annual soil losses for specific combinations of physical and management conditions on a site specific basis. The equation was not designed for use at regional levels but, because it is the best and simplest available tool, it has traditionally been used for both local and broad-scale analysis (Foster et al. 1985).

American researchers have noted certain deficiencies in the USLE and the equation has been modified slightly over time. Foster et al. (1985) discussed modifications that improved the equations ability to estimate erosion from single storm events, to estimate sediment yield and to differentiate between rill and inter-rill erosion. The literature suggests that there are questions associated with the universal applicability of the U.S.L.E. in the United States, but that it is generally held to be unsurpassed in utility by any other existing methods.

In Ontario, the Universal Soil Loss Equation has been used extensively in the prediction of both existing and potential rates of erosion at large and small scale. Wall and Driver (1982) have used erosion rates determined by the USLE to predict the costs of soil erosion on the agricultural industry due to yield and nutrient losses. Annual cropland soil erosion costs were estimated to be $68 million with 80% of this loss occurring in Southern Ontario.

Scientists have attempted to improve the applicability of the USLE in Ontario by incorporating and accounting for the erosive effects of snow melt in the R (rainfall and runoff) factor in the equation. This was accomplished by adjusting rainfall erosion indices for winter months (Wall et al. 1983). Dickinson and Pall (1982) have also examined the erodibility factor (K) of the USLE and concluded that it is seasonally variable with peak erodibility occurring in late winter and early spring, under frozen soil conditions. They note that erodibility varies most dramatically on wet, loose silt loam with impeded internal drainage. Such conditions are typical of the winter-spring transition period characteristic of Ontario. American scientists also acknowledge that the USLE in its original form does not properly account for frozen soil conditions (Foster et al. 1985). A survey of the literature indicated that winter rainfall indices had been corrected in the Pacific Northwest and the mountainous areas of California, to account for the erosive effects of snow melt (Evans and Kalkanis 1977).

However, no studies relating to the impact of freeze-thaw on soil erosion have been found.

A methodology for mapping provincial soil loss potential has been developed at the University of Guelph (Shelton et al. 1985). The development of this approach recognized 1) the value of comprehensive regional planning in the delivery of soil conservation programs and 2) the lack of a sizeable and/or consistently derived data base of measured erosion, suitable for use in broadscale planning. This methodology was designed to facilitate a standardized

examination of predicted soil loss from relatively homogeneous soil landscape units within a regional context (Shelton et al. 1985). The Universal Soil Loss Equation is again used as a quantitative framework. Information required as input to the equation is available on a province wide basis. With the use of standardized procedures for determining representative site conditions, information is readily comparable between map units, thus allowing a ranking of problem areas. Counties with the highest potential for erosion were Middlesex, Brant, Oxford, Perth, Huron, Waterloo and Wellington (Shelton et al. 1985). This methodology provides a useful indication of relative conditions and is appropriate for use in broadscale examinations.

The Universal Soil Loss Equation has also been used in conjunction with crop yield models to predict potential average yield loss on specific soils in Huron County (Land Evaluation Group 1985). In this study, the LEM 2 grain corn productivity model, developed by the Land Evaluation Group at the University of Guelph, was used to estimate yield given soil characteristics, climatic conditions and farming practices. A discussion of LEM 2 and its possible application is presented in Smit et al. (1981). The USLE was used to estimate expected erosion on 13 selected Huron County soil series if continuous corn were grown for 25 years. In recognition of the non-uniform nature of erosion in complex topography, the estimated soil loss was assumed to occur from 25% of the area. Subsequent application of LEM 2 provided information on expected yield reductions on selected soils. The yield - related implications of the study will be discussed later in this report. With respect to soil erosion it was found that expected soil losses under the assumed conditions ranged from 2 cm to 60 cm thus illustrating the soil specific variability of erosion. The study also highlighted the variability of soil loss tolerance between soils (Land Evaluation Group 1983). This variability will be discussed in section 2.2.

Research conducted 1982-83 in Wellington Co. and Waterloo Region revealed that actual measured in-field erosion on specified plots was many times that which would be predicted by the USLE (Battiston and Miller 1984, Battiston et al. 1987). Current studies underway in Brant County by Kachanoski and co-workers indicate instances of localized measured erosion which greatly exceed USLE predictions. Revelations such as this draw into question the validity of the equation for prediction of soil loss on specific sites. Among possible explanations for this apparent failure of the USLE are freeze-thaw processes and tillage translocation.

The freeze-thaw process is a potential contributor to locally excessive rates of soil erosion. Repetitive freezing and thawing of surface soil, overlaying frozen subsoil, contributes to dislodging of soil particles and their subsequent movement. Unfortunately, a survey of the literature did not yield any studies, Canadian or American, which have examined the role of the freeze-thaw process.

Tillage translocation involves the movement of soil by tillage - particularly conventional tillage. Quantities of soil may be moved downslope by cultivation practices (both plowing and disking). Piest et al. (1977), in a study conducted on loess hills in Western Iowa, found that the amount of soil moved downslope by cultivation practices during a five-year study period were as great as downhill soil movement by normal erosion processes. Kiss et al. (1986) determined in a Saskatchewan study that the greatest erosion rates occurred on the upper slope positions. They attributed this erosion to a combination of wind and tillage. Little information is available on tillage translocation. Aside from identifying this process, and the freeze-thaw effect, as possible causes of localized excessive erosion little more is possible at this time.

The aforementioned study by Battiston and Miller disputed a second premise of the USLE - that uniform rates of erosion occur on all areas of a given slope. This study found that severe erosion occurred in small areas and was particularly prevalent on knolls and shoulders of slopes (Battiston and Miller 1984, Battiston et al. 1987). In-field variations in erosion were found to be dramatic on rolling topography. Similarly, a study conducted in North Carolina by Daniels et al. (1985) reported that the distribution of erosion classes (phases) on the landscape contradicted predictions based on the USLE. While the equation predicted more erosion on the longer slopes, results showed that 49% of soils on interluve, shoulder and linear slope positions were severely eroded.

In light of these and other observed patterns of erosion, it appears that the assumption in the USLE that erosion rates are constant in any slope position is invalid. The actual mosaic of erosional phases is non-uniform and has significant implications for field management.

American researchers note additional limitations and concerns regarding the USLE. They are summarized by Crosson and Stout (1983) and include under-estimation of erosion because of snow melt, underestimation of erosion on shallow soils because of lower infiltration, the fact that the equation was originally based on midwest soil and climate conditions and the fact that input data to the equation is often generalized or inconsistently derived. Nevertheless, the Universal Soil Loss Equation has been, and continues to be, the fundamental tool used in the prediction of erosion at both local and regional levels. It provides reasonable estimations of relative rates of erosion and is easily used in the field by soil conservation specialists (Foster et al. 1985).

2.2 Soil Loss Tolerance

The sensitivity of soil to yield reduction as a result of erosion is determined, to a very large extent, by its physical properties. The maximum annual rate of erosion that will allow a high level of crop productivity to be maintained economically and indefinitely is defined as "tolerable soil loss" or T-value (McCormack et al. 1982). Despite the importance of this concept, information on soil loss tolerance in southern Ontario is very limited. The maximum rate of annual soil loss which will allow the maintenance of long term productivity is generally accepted to be 7 tonnes per hectare.

Research conducted in Waterloo Region in 1982-83 by Battiston and Miller demonstrated a wide variability of T-values between individual soil series. Corn yield reductions after similar amounts of soil loss ranged from 12% on a Brant Silt Loam to 78% on a Burford Sandy Loam (Battiston et al. 1987). Similarly, a study of Huron County soils conducted at the University of Guelph (Land Evaluation Group 1983) indicated that a single value of 7 tonnes per hectare did not adequately reflect the sensitivity of all soils to long term reductions in potential productivity. Although this study assessed only changes in physical soil properties (i.e. assumed optimum cropping and management conditions) it clearly established the variability of T-values on 13 soil types. Estimated soil loss ranged from 5 to 60 cm whereas estimated reduction in corn yield ranged from 0 to 1929 kg ha^{-1}. Based on these two studies alone, it is clear that average T-values, while of some use for broadscale analysis, are not satisfactory for specific locations.

Also included among the significant findings of Battiston et al. (1987) was the discovery of critical "total-soil-lost" levels. Little, if any yield reduction occurred with erosion until approximately 50% of the upper horizons had been lost. Continued erosion was marked by dramatic yield reductions. This study clearly illustrated the non-linear nature of the soil loss - yield reduction relationship and suggests that T-values must acknowledge the existence of critical soil loss levels on individual soil types (Battiston et al. 1987). The fact that an existing constant rate of erosion has not caused yield reduction does not imply that such a rate of loss is tolerable. The only reliable method of utilizing the concept of T-values is to determine such values on a soil-specific basis (Miller 1984).

In the United States, the concept of tolerable soil loss is one which has been utilized since the 1940's (McCormack et al. 1982). Tolerable values have been used as planning tools or targets for program managers, although their attainment has never been legislated. Guidelines for establishing T-values have been established and revised over many years. Current values used by Soil Conservation Service field advisors range from 2.2 t/ha on soils with less than 25 cm of rooting depth to 11.2 t/ha on soils with greater than 152 cm rooting depth (McCormack et al. 1982). A review of the literature suggests that the concept of T-values, and the manner in which they are defined, has been the subject of considerable debate in the United States. Possible considerations in the setting of T-values include crop productivity, sediment yield, and phosphorus yield. McCormack et al. (1982) note that increased knowledge regarding the rate of top soil replacement, and the effects of erosion on productivity are essential to the determination of T-values based on yield maintenance. These authors further note that the inclusion of water quality objectives greatly complicate the T-value equation because of 1) the complexity of delivery-ratios, and 2) past uncertainty in the establishment of water quality objective at both local and regional levels. For these reasons the Soil Conservation Service in the United States has eliminated off-site sediment damage from their criteria for determining T-values (McCormack et al. 1982).

McCormack et al. (1982) indicate that erosion on most cultivated sloping soil exceeds the rate of root zone formation. While T-values can be established on technical grounds alone, most authors conclude that ethical, economical and political consideration must also be addressed (McCormack et al. 1982, Nielson 1986). Two options, currently being discussed in the U.S., are the establishment of multiple T-values and the establishment of T-values based on technical criteria, which are not consistent with conservation objectives.

Nowak et al. (1985) and Larson (1981) discuss the concept of multiple T-values. Briefly, this involves a T-value, based on the technical aspects of productivity maintenance over a specified time-frame (planning horizon), and a second T-value which accounts for the social, economic and political costs of achieving tolerable soil loss (Nowak et al. 1985). This second T-value acknowledges that what is appropriate from a soil science perspective may not be attainable in reality because of socio-economic constraints. In a similar vein, McCormack et al. (1982) discusses the merit of T-values which reflect long-term soil productivity and acceptable sediment yield levels. They note that the subsequent development of "conservation objectives" would be based on the degree to which social and political groups are prepared to achieve tolerable soil loss rates. In summary, the literature regarding soil loss tolerance suggests that it is the aspect of soil erosion, more than any other, which is sensitive to both technological and socio-economic considerations. With regard to technical improvements it is evident from studies completed in Ontario, elsewhere, that single or

broadscale T-values do not adequately reflect the sensitivity of individual soil types to erosion. It is also apparent that rates of soil loss and yield reduction are non-linear and that effective field scale soil conservation efforts must recognize not only the sensitivity of soil types but also the proximity of erosional sites to the critical soil loss levels discussed earlier. Further, the establishment of T-values which are appropriate for both crop productivity and water quality objectives requires understanding of both the soil erosion - crop yield relationship and the soil loss - delivery ratio relationship. These will be discussed later in this report. The literature also highlights the complexity of tolerable soil erosion and the social, economic and political considerations which contribute to its attainment.

2.3 Causes of Soil Loss and Yield Reduction

A stated at the outset of this report, the identification and implementation of effective remedial measures depends greatly on the degree to which soil conservationists understand contributing physical processes and associated impacts. Knowledge of these two areas will facilitate the selection of either corrective or preventative remedial measures. Corrective measures are those which are designed to restore yields on currently eroded soils. In order to prescribe effective corrective strategies it is necessary to establish the causes of yield reduction. Preventative measures are defined as those which address the soil erosion problem itself; they are long-term treatments designed to prevent further erosion and future yield reduction. The development of effective preventative measures must be preceded by an understanding of the processes and causes of soil erosion at both regional and site specific levels.

2.3.1 Causes of Yield Loss

The primary causes of erosion-induced yield loss are generally held to be nutrient deficiency, structural degradation and loss of available water holding capacity (Langdale and Shrader 1982, Battiston et al. 1987). Two possible management responses to declining yield are to 1) adopt management practices which offset the effects of erosion on yields and 2) to lower erosion to a rate which permits the maintenance of soil structure and other soil properties (Crosson and Stout 1983).

The literature supports the notion that soil erosion reduces productivity by removing nutrients, and that this can, in many cases, be corrected by replacing the lost nutrients with fertilizer (Langdale and Shrader 1982). In Ontario, only two studies had been reported, prior to 1980, relating crop yield to the severity of erosion. In 1982-83 Battiston and Miller (1984) conducted extensive field work in Wellington County and Waterloo Region to examine the extent and distribution of erosion and the yield related impacts of soil erosion. Seventeen sites, exhibiting varying degrees of erosion, were studied. Eroded plots possessed lower fertility and lower available water holding capacity than non-eroded plots (Battiston and Miller 1984). Organic matter content was lower and surface structure less desirable with erosion. This study found that, while nutrient deficiencies limited yield, they were rarely the only limiting factor present. As noted above, the study found that erosion was not distributed evenly, but occurred in small isolated areas. This scattering of erosional areas within a field poses problems for the treatment of nutrient deficiencies with fertilizer application. Obviously, a uniform application of fertilizer will not be appropriate for all areas within a field; but variable rate applications present technological and management challenges which present research has not fully addressed.

Many studies have been conducted in the United States relating nutrient deficiency and yield reduction. The bulk of this work was conducted in the 1950's and 1960's and is well summarized by Crosson and Stout (1983). Almost all of these studies compared yields on top-soil and subsoil and found that, when nutrient deficiency was the dominant limiting factor, yields could be brought up to, or close to, yields on non-eroded top soil. Loss of available water holding capacity (AWHC) is also identified as a cause of yield reductions. Recent erosion productivity research in the United States suggests that the reduction of AWHC is a more serious problem than nutrient deficiency (Larson 1981). The literature indicates that AWHC of eroded soils is frequently less than that of non-eroded soils and that it is more difficult, or sometimes impossible, to correct nutrient deficiencies when they are accompanied by unfavourable sub-soil conditions (Crosson and Stout 1983). In Wellington County and Waterloo Region, Battiston and Miller (1983) found that eroded sites possessing coarse textured subsoils were unable to retain water and therefore unable to retain applied nitrogen because of rapid leaching. Similarly, they found a high correlation between available water holding capacity and yield at sites where moisture stress was identified as a problem.

Ontario scientists have stated that lost available water holding capacity, due to coarse or dense subsoil, will eventually result in permanent and irreversible yield loss (Battiston et al. 1987). American scientists such as Langdale and Shrader (1983) and Young (1980) substantiate this position and state that on deep, medium textured soils principal damage is expected to be loss of nutrients. However, technology will have little effect on

the processes by which soil is formed at the base of the root zone. Consequently, where erosion narrows the root zone sufficiently to reduce AWHC, technology cannot compensate for the adverse yield effect (Young 1980). Crosson and Stout (1983) report on a study by Batchelder and Jones (1972) in the U.S., which examined the effects of management practices in improving the productivity of subsoils by increasing their available water holding capacity. They found that a regime of liming, fertilization, mulching and irrigation could be used to improve yield. While such measures may be of benefit from a technical view point, they are not realistic for landowners because of prohibitive cost.

Structural degradation of Ontario soils has been identified as a third cause of yield reduction. Structural degradation is characterized by poor drainage, ponding and poor seedling emergence. In the same manner as lost fertility and reduced available water holding capacity, structural degradation has been noted as a cause of yield reduction in Wellington County and Waterloo Region (Battiston et al. 1987). This was due to a blocky open structure in the surface horizons of eroded plots, which resulted in poor seed-soil contact.

Soil structure is a major factor determining the ability of a soil to allow water to infiltrate and to provide adequate aeration (Crosson and Stout 1983). Structural degradation of a soil generally results from compaction and/or loss of organic matter. Little documentation exists regarding the extent of soil compaction in Ontario (Miller 1984). Miller (1984) reports that increasing numbers of farmers now complain of soils which are difficult to cultivate and drain.

The impacts of compaction have been studied at the University of Guelph. Ketcheson (1980) reported observations of diminished structural stability on continuous corn as opposed to forage-based rotations in the 1950's. Several Ontario studies completed since that time substantiated those findings. Vyn and Daynard (1984) have investigated the effect of alfalfa on aggregate stability and have reported that 2 to 4 consecutive years of alfalfa caused marked increases in stability whereas 2 years of soybeans resulted in decreased stability, relative to continuous corn production. However, the improved stability observed when alfalfa was grown did not persist once the alfalfa was plowed under and corn was produced instead. Angers et al. (1987) studied the effect of four different cropping histories on aggregate strength. The cropping histories ranged from 15 yr of continuous corn to 15 yr of continuous bromegrass. Changes in structure as measured by aggregate strength and inter-aggregate porosity appeared to occur rapidly when cropping practices changed, increasing rapidly when bromegrass replaced corn and decreasing rapidly when corn replaced bromegrass.

Findings, such as those noted above, suggest that methods are available to combat structural degradation. While specific measures will be discussed in a following section, it is worth noting that, unlike loss of available water holding capacity, it is technologically feasible to correct this cause of yield reduction.

2.3.2 Processes of Soil Loss

The foregoing discussion of the causes of yield loss was based on the need to identify corrective measures which are designed to alleviate this major problem related to soil erosion. In addition to quickly restoring soil productivity, conservationists must also attempt to halt the underlying soil erosion problem through the application of preventative strategies. In order to devise the most effective strategies it is necessary to examine the processes associated with soil loss. These are detachment and transport. Detachment requires energy which is provided by falling raindrops and flowing water (Wischmeier and Smith 1965). Soil aggregates are broken down by the impact of raindrops and primary particles are detached from the soil mass. Much of the raindrop energy may be spent in puddling and sealing of the soil surface, thereby increasing overland flow. Given the erosive power of rainfall, the amount of detachment which actually occurs closely relates to the extent to which the soil surface is protected from raindrop impact. A complete canopy such as that provided by grasses, leaves etc. will absorb much of the available raindrop energy and thus reduce detachment. The canopy's ability to prevent detachment has been shown to be inversely proportional to its height above the soil surface (U.S. Department of Agriculture 1978). The U.S.D.A. contends that a canopy covering 80% of the surface, at a height of 4 metres will reduce erosion by 20%. In contrast, a full covering of mulch at the surface will reduce erosion by 95%. While these figures represent a broad generalization, they are indicative of the significance of surface protection. In addition to lack of surface protection, soils which are susceptible to detachment are also characterized by poor surface structure.

When rainfall intensity exceeds the infiltration rate plus surface detention, excess water moves downslope as runoff and provides transportation for soil particles (Begg , Wischmeier and Smith 1965). Overland flow of water is generally held to be the primary method of transport in Ontario. As noted above, it is associated with poor infiltration, poor subsurface drainage, and concentration of flow. Poor infiltration is associated with frozen subsoil, surface crusting and/or surface compaction. A review of the literature reveals that essentially no information is available in Ontario on the impact of frozen subsoil and the freeze-thaw period on soil transport.

Poor subsurface drainage is due to naturally impervious subsoils or subsoils which have been rendered impervious by man. In Ontario, existing knowledge of surface soil and subsoil characteristics provides information on the location of naturally compact subsoil but no studies have examined the extent and distribution of man-induced subsoil compaction (Miller 1984). Concentration of flow is a major cause of soil transport and is associated with uncontrolled runoff and sloping topography.

Finally, transport by wind is also possible on Ontario soils. Wall and Driver (1982) concluded that wind erosion accounted for only 2% of annual costs associated with cropland erosion in Ontario. In localized situations on sandy soils, however, damage can be severe. Transport of soil by wind is related to inadequate surface protection, the removal of fence rows and windbreaks and excessive secondary tillage (Miller 1984). In a survey conducted by Fitzsimmons and Nickling (1982), directors of Soil and Crop Improvement Associations in Ontario indicated that wind erosion was an observable problem on coarse textured soils in Kent, Elgin, Essex and Haldimand-Norfolk Region. Corn was the dominant crop on fields in which wind erosion had been observed although other crops are likely to suffer made from the abrasive effects of wind erosion (eg tobacco, tomatoes and beans). Wind erosion can also be significant on organic soils used primarily for vegetable production in the Holland Marsh, Erieau and Thedford area. Little research has been conducted on erosion caused by wind on Ontario cropland. This is due, largely, to the relative insignificance of this form of erosion in Southern Ontario.

The susceptibility of a soil to be detached and transported is defined by Wischmeier and Smith (1965) as its erodibility. Soil erodibility is a key input to the Universal Soil Loss Equation and has been studied in Ontario and elsewhere. Dickinson and Pall (1982) examined the erodibility of Brantford Clay Loam, Fox Sandy Loam, Haldimand Clay (silty clay) and Fox coarse sand. This study examined, among other things, the seasonal variation of erodibility and confirmed that greater levels of detachment and transport occurred after rainfall and/or snowmelt on soils having frozen (i.e. impervious) subsoils. Significantly higher rates were also associated with rainfall on recently tilled or thawed surface soil. Dickinson and Pall (1982) further observed that variation of erodibility was greatest on fine textured silts and clays.

2.3.3 Effect of Erosion on Crop Productivity

Based on general understanding of the process of soil erosion and the causes of yield loss it is possible to examine their relationship and to quantify the effect of soil erosion on productivity. Methods which have been used to study soil erosion and productivity have fallen into three broad categories; scalping, direct field measurement and computer modelling. Battiston and Miller (1983) provide a useful review of each of these techniques. The following has been largely derived from their presentation.

Scalping consists of mechanically removing topsoil from a non-eroded soil. Yields are compared between mechanically desurfaced and unaltered soils. This approach was used by Ripley et al. (1961) and Englestad et al. (1961). Utilizing this method, variables in the experiment can be closely controlled. Unfortunately the physical removal of a surface horizon does not reflect the consequences of gradual natural soil erosion.

Direct field measurement involves monitoring crop growth and yields on eroded and non-eroded soils under typical field management conditions. The advantage of this method is that it occurs under actual field conditions. As mentioned earlier in this report, only one study in Ontario has involved detailed field checking on an area. Battiston and Miller (1984) found that, over a two-year period, grain corn yield on moderately to severely eroded soil was on average, 30% lower than on areas that had experienced little or no erosion. This method of measuring yield loss, while reliable, is not frequently employed because of time and cost. This was discussed in section 2.1 of this report.

Computer modelling has become more prominent in recent years. As noted earlier in this report, the alternative to direct measurement is prediction and estimation. These tools are needed for broad-scale analysis and represent efficient approaches to assessing soil erosion and yield loss. Much of this material has already been introduced in the earlier discussion of the measurement and prediction of erosion, and will therefore, be only briefly mentioned here. McBride and Mackintosh (1984) have developed a grain corn productivity model based on regression analysis. The model uses the USLE to estimate the quantity of soil loss that will occur on a given soil over a specified time period. It has been effectively used to estimate the effects of 25 years of erosion on 13 Huron County soils. The results of this work were summarized above.

In the United States, most early studies involved desurfacing or scalping. After 1960, field based experiments have increased in numbers. Meyer et al. (1985) provides an excellent insight into past research efforts in the U.S. and discusses the advantages and disadvantages of each form of analysis. This discussion, while very interesting, is extensive and is therefore not summarized here.

The most significant development in the United States regarding the assessment of the soil loss - yield reduction relationship has been the development of the Erosion - Productivity Impact Calculator model (EPIC). EPIC is a mathematical model for simulating erosion, crop productivity, and related processes. The intended use of the model is to determine the relationship between erosion and productivity (Williams and Renard 1985). Williams and Renard (1985) provide a detailed technical analysis of EPIC'S component parts. This paper, along with the numerous references contained therein, should be consulted by those requiring detailed information on the model.

EPIC is a very extensive process model. It consists of 53 sub-routines and 2700 Fortran Statements (Williams and Renard 1985). Its sub-routines deal with soil, water and nutrient budgets, weather simulation, tillage and residue management simulation, bio-mass crop growth simulation, soil erosion simulation and production budget costs (Crosson and Stout 1983).

The EPIC model is currently operational and has produced reasonable results under a variety of climatic conditions, soil characteristics and management practices (Williams and Renard 1983). We acknowledge the comprehensive nature of EPIC but question its practical applicability because of the formidable data demands of the model. The major limitation of all models is that they require extensive field data for development and validation (Meyer et al. 1985).

2.4 Remedial Measures

The preceding sections of this review established the economic and environmental significance of soil degradation, particularly soil erosion. The processes that cause soil erosion and the effects of soil erosion, including the loss of nutrients, organic material and soil (all resulting in loss of productivity), along with the measurement and prediction of soil erosion were also examined. The need for remedial measures was expressed.

An understanding of the processes that cause erosion in southwestern Ontario and an appreciation of its effects allow the development and the implementation of corrective and preventative remedial measures. Reducing soil erosion will maintain and possibly improve the soil productivity and water quality in this region. There are six broad categories of remedial measures that may be utilized to reduce soil erosion and its effects.

1. Surface flow control
2. Subsurface flow control
3. Cropping systems
4. Tillage systems
5. Compaction control
6. Amendments

The interrelationships and interdependencies of many of these measures usually necessitates the application of more than one measure at a time, especially with cropping and tillage systems.

The utility of these remedial measures is dependent upon their effectiveness and acceptability. The relative effectiveness of the remedial measures varies with the cause of soil erosion whether it be related to slope characteristics or compaction. The acceptability of the remedial measures is dependent upon their affordability and profitability and the social ramifications of management modifications.

The adequacy of the literature to address these issues as they relate to southwestern Ontario is often insufficient. This only strengthens the need for more studies on soil erosion in the region.

2.4.1 Surface Flow Control

Surface flow of water is responsible, in part, for the dislocation of sediment and for the transportation of eroded materials. There are several methods of controlling runoff flow, thereby controlling soil erosion and its effects. The severity of the problem is related to the degree and the length of slope and the surface condition. Any reduction in the velocity and/or the concentration of runoff will reduce the erosive power of the water. The power of the surface flow can be reduced with either cropping and tillage practices or flow structures.

Cropping and tillage practices that increase the quantity, quality, duration or timeliness of ground cover can effectively reduce the erosive force of surface flow. Selective cropping, underseeding and interseeding, and the utilization of reduced tillage or no-till are all effective methods of improving the protective nature of the ground cover. The effectiveness of cropping and tillage practices in reducing soil losses can be increased with contour cropping and strip cropping. These practices and the examination of the pertinent literature are discussed in more detail in following sections.

Flow structures are the most permanent and often the most expensive remedial measure for controlling soil erosion. Their use is usually limited to severe erosion problems such as gullies. Surface flow structures are site specific and are dependent upon the nature of the erosion problem.

Structures commonly used in the control of surface flow in southwestern Ontario include:

1. berms and diversion terraces
   - retain surface flow and decrease the slope length
2. grassed waterways and diversion channels
   - concentrate flow into protected channels
3. sediment or catch basins
   - retain surface flow

These structures are usually used in conjunction with subsurface drainage such as drop inlets. More extensive structures, such as terraces, are not commonly found in southwestern Ontario because of the difficulties associated with the region's complex topography as well as prohibitive costs for installation.

Research into the technical aspects of surface flow structures has been well established. The Soil Erosion Manual printed by the Ontario Ministry of Agriculture and Food, (1985) contains a comprehensive discussion of surface flow control structures. Included are detailed technical descriptions of vegetative and non-vegetative materials, design, relative effectiveness, and relative costs of grassed waterways, open ditches, drop structures, stream bank outlets, field terraces, diversion terraces, and water and control basins. This manual supplies the pertinent information on which to base the choice and dimensions of flow control structures in Ontario.

A cost analysis of several erosion control structures on three sample farms within the Rondeau Bay watershed is contained in the Master Erosion Control Plan for the Rondeau Bay Watershed prepared by Ecologistics Limited (1983) for the Ontario Ministry of the Environment. This report provides good examples of total capital costs and annual cost for various structures utilized to control soil erosion on the rolling loam soils of southwestern Ontario. Studies conducted by the EPA in the United States have also examined the effectiveness and the cost of implementing various flow control structures (Clark et al. 1985).

The Ecologistics report noted that the main limitation of surface flow control structures as compared to other soil erosion control measures, was the higher costs involved. Other considerations, beyond material and construction costs, that affect the acceptability of surface flow structures are maintenance, management problems, and the loss of productive land. The effectiveness of structures in erosion control, however, is virtually unlimited.

The long-term benefits of reduced erosion may not always justify the short-term expense of flow structures, especially with an inflationary economy. The Ontario government has recognised this situation as a problem and has made assistance available in the form of loans and grants such as OSCEPAP II. Government assistance is proving successful in improving the acceptability of flow structures.

2.4.2 Subsurface Flow Control

The ability of water to flow through the soil determines the amount of runoff, and hence erosion. The nature of this subsurface flow is determined by the texture and the structure of the soil, and its topography. The soil's natural drainage can be impeded by compaction: the degradation of the soil structure resulting from mechanical or chemical causes. Excessive tillage and traffic are responsible for pulverizing the structure of the soil. Porosity and aggregate size decrease and compaction results. Excessive oxidation and mineralization of organic matter combined with low organic returns lower the soil's organic matter content also resulting in the degradation of the soil. The organic matter (and particularly the polysaccharides and other active constituents of organic matter) is responsible for maintaining the integrity of the soil structure and when levels are low, compaction is promoted and erosion increases. Cropping and tillage systems are responsible for reductions in the organic matter content of the soil.

Improving the natural drainage of the soil or enhancing the existing drainage can effectively reduce the amount of erosion. The soil's natural drainage can be improved by reducing compactive activities, enhancing loosening associated with freeze thaw cycles and reducing organic matter losses by minimizing tillage or introducing crops that improve the soils natural drainage. The method, effectiveness and acceptability of such measures are discussed in the section entitled Compaction Control. Subsurface flow can be enhanced with tile drainage or drainage ditches. The potential of drainage in reducing soil erosion has been examined by Drablos and Jones (1981). This form of remedial measure has more immediate effects but it does not prevent the infiltration problem caused by surface soil degradation. Ditching and draining may be the only remedy on fine textured, poorly drained soils where subsurface flow can not be naturally improved.

Tile drainage and drainage ditches have been widely adopted throughout southwestern Ontario because they are effective in increasing subsurface drainage, have improved field timeliness, increased crop yields because of loan assistance provided by the provincial government.

2.4.3 Cropping Systems

Cropping systems in southwestern Ontario generally involve the rotation of a narrow range of field crops. Crop

rotations may include many permutations of crop sequence. Crop rotations commonly found in southwestern Ontario, in order of their relative frequency as determined by Wall et al. (1984), include:

1. row crops and cereals
2. row crops, cereal and forage
3. row crops
4. row crops and forage
5. cereal and forage

The crops included and the duration of the sequence is strictly a managerial preference involving many factors such as relative profitability, pest control, nutrient levels, pesticide residues, labour distribution, and productivity. Erosion control has only recently been a major consideration when planning a cropping system.

The production of any grain crop requires a reduction in the amount of ground cover from that of natural field conditions. This reduces competition, controls disease, and makes many managerial functions such as weed control easier. Reducing the amount of ground cover leaves a greater proportion of the soil unprotected from erosive elements thereby increasing erosion. The problem of erosion is compounded by tillage and its effects on the soil. Cropping systems have conventionally involved intense cultivation. Tillage practices, their impact on erosion, and their relationship with cropping systems are discussed in the following sections. A good ground cover, which includes vegetation cover and/or residue, effectively controls erosion because it reduces the amount and concentration of wind and water flow over the surface, and stabilizes the soil making it less erodible. The ground cover also absorbs the energy of the falling rain drops which are the major cause of soil particle dislocation. Canopy cover is most effective in this capacity when it completely covers the soil surface below. The lower the cover is to the ground the more effective it is in absorbing the total rainfall energy before it reaches the soil. Complete ground cover at ground level can reduce erosion by up to 95 percent (Wischmeier and Smith 1978). The effectiveness of the ground cover is most easily observed on steep slopes.

The choice of crop determines the quantity, quality, duration and timeliness of the canopy cover. The choice of crop also affects the nature of the residue. Some crops produce more total residue and some decompose more slowly because of high carbon-nitrogen levels (Mannering and Johnson 1976). The amount of residue is largely determined by the tillage practices associated with the cropping system.

Forages are the most effective crop in reducing soil erosion because they have an extensive root network, sustain dense growth throughout the growing season, have a long growing season, supply a good ground cover throughout the winter, and are close to the ground. The inclusion of perennial forages into a cropping rotation is regarded as a very effective erosion control measure (Ketcheson 1977, Wischmeier and Smith 1978, Ketcheson 1980). The positive residual effect of a grass-legume meadow which is tilled diminishes within a 2 to 3- year period. A mixture of grasses and legumes were more effective than legumes alone (Wischmeier and Smith 1978). Even the inclusion of small grains into a row crop rotation can be an effective measure in reducing soil erosion. Row crops are most conducive to soil erosion because they are seasonally grown, provide only partial canopy cover during much of the growing season, and provide channels for concentrated flow. Limiting the number of years of row crops in rotation, particularly of corn and soybeans, would definitely be beneficial to soil erosion control, but the relative profitability of some row crops, their importance as livestock feed, and the need for crop diversification make that an unacceptable measure.

There have been several studies conducted in southwestern Ontario that demonstrate the detrimental effects of a continuous corn rotation. On more sloping, medium textured soils in continuous corn, Webber (1964), measured soil losses as high as 70 tons per acre in a single year. Corn in rotation with a sod crop suffered less than one third of this soil loss. Runoff plots at Guelph and Ottawa have shown that the rotation of corn, cereals, and hay can reduce soil and water losses to a fraction of the losses with continuous corn. A corn-oats-hay-hay rotation had one-tenth and one-third the soil losses as compared to continuous corn on loam and clay soil respectively (Ketcheson 1977). Yield benefits were also shown possible from improved soil physical conditions and nutrient supplies (Webber 1964). Results obtained from a study by Baldock and Kay (1987) indicate that 15 years of continuous grain corn production using conventional tillage practices significantly reduced the size and water stability of soil aggregates relative to 15 years continuous bromegrass production. Probably of more importance is the fact that the rate of loss of structural stability induced by grain corn production was faster than the rate of gain induced by bromegrass production. A similar study on the effects of crop sequence on soil structure, stability and productivity was conducted by Vyn (1987). Tests were performed on two sites between 1980 and 1985, one a silt loam soil near Elora and the other a clay loam near Milton. Soil cropped with continuous alfalfa was consistently higher in structural stability than soil in continuous corn. Interestingly, soil structural stability during the first year of alfalfa was not significantly better than that of continuous corn. This indicates the cumulative nature of costs and benefits associated with these two extremes. Vyn (1986) also found that in a short term rotation, corn yields could be

maintained so long as corn followed something other than corn. Apart from soil degradation and soil loss, continuous corn production suffers substantial yield losses under no-till on poorly drained soil. A rotation of crops was found to remedy the yield losses of continuous corn on poorly drained soils (Van Doren et al. 1976, Dick et al. 1986). More research is needed on crop rotations other than continuous corn. Wall et al. (1984) note that continuous corn accounts for only 8% of cropland in southwestern Ontario. Continuous corn has been given a disproportionate amount of attention.

One rotation which is worse than continuous corn, is a soybean-corn rotation. Researchers in Iowa have shown that plots planted to corn following soybeans were 40% more erosive than situations where soybeans followed corn or corn followed corn using conventional tillage (Mannering and Johnson 1976). Soil losses in the spring are much greater following a crop of soybeans than following a crop of corn. Soybeans do not produce a large amount of residue and the residue which is produced decomposes faster, in part because of a low carbon-nitrogen level. Soil aggregate stability is also generally lower after soybeans than after corn (Bathke and Blake, 1984; Kladivko et al., 1986). Mannering and Johnson suggest that the residual effects of the previous crop may have more influence on soil erosion than the present crop. This has significant ramifications when considering tillage systems.

Crop rotations can also reduce production costs. Rotations disrupt weed, disease and insect cycles, reducing the need for high pesticide application (Clark et al. 1985). A short term profit may not be seen unless there is a market for all the crops in rotation.

The pronounced seasonal climate of southwestern Ontario results in seasonal erosive activity. Soil is most susceptible to erosion in the spring, following freeze-thaw processes and when precipitation is high (Dickinson and Pall 1982). For this reason the duration and the timeliness of the ground cover is of the utmost importance (Frye et al. 1985). Consideration of these facts has led to the modification of standard cropping systems beyond the simple inclusion of forages and small grains. Underseeding and interseeding have become popular methods of reducing soil erosion, particularly at critical times of the year, and retaining row crops in rotation (Wischmeier and Smith 1978, Clark et al. 1985). Underseeding is the growth of a dense low-lying secondary cover crop, such as red clover, rye, vetch and alfalfa, under a more predominant primary crop, such as wheat or corn. Underseeding is already a common practice with winter wheat production;p research indicates that higher soil aggregate stabilities are achieved when wheat is underseeded with red clover than when wheat is not underseeded (Vyn, et al. 1984). Interseeding confines the secondary crop to the inter-row space of wide-spaced row crops such as corn and soybeans. Studies into the relative success of red clover and alfalfa interseeded into corn at the University of Guelph, by Vyn et al. (1984), found that red clover established a better stand and achieved higher yields than alfalfa when interseeded. However, corn yield depressions were sufficiently high to discourage this practice in grain corn production. Research by Sheard (1986), also at Guelph, on silage corn underseeded with red clover concluded that red clover reduced the nitrogen requirements of the corn, but the monetary gain derived from the reduced N requirement was counter-balanced by the slight yield depression. The benefit was insufficient to pay for the cost of the red clover seed. The benefit of reduced soil loss was not assessed.

These secondary crops remain through the harvest of the primary crop and persist as a protective cover until late fall or spring when they are killed and plowed down. Competition problems are reduced by planting slowly developing secondary crops with the primary crop or planting after the primary crop has been established. Vyn et al. (1983) noted that when alfalfa and red clover were seeded on the same day as corn, corn yields were significantly lower due to competition. Later interseeding was found to reduce competition but establishment of the legume was also much more erratic.

As well as reducing erosion, underseeded and interseeded cover crops provide substantial amounts of organic material and, in some cases, nitrogen to the soil. However, the presence of a cover crop may result in conditions that are conducive to weeds, diseases, and insect pests (Power 1983). Power notes that research on legume/weed-disease control is limited. Research at Michigan State University has demonstrated that rye residues release chemicals which suppress the growth of certain weeds. Certain types of wheat and sorghum were also found to have this effect (Anon. 1984). The effects of various cover crops on management practices need to be examined in greater detail.

The production of phytotoxins from cover crops is a matter of concern. Prior to planting, the cover crop is killed by tillage or herbicide application. During decomposition, components in the decompositionary chain may accumulate to toxic levels. The rate of decomposition, and hence phytotoxin production, is dependent on soil climate relations and therefore is very site specific. Corn yield reductions of 10 to 25% have been observed at Elora and Woodstock following fall rye cover crops (Muldoon et al., 1985). Corn yield reductions were observed whether the rye was plowed, disced or chemically controlled. Preliminary studies are being conducted by the University of Guelph in Huron county

on phytotoxin production in wheat stubble and its affect on no-till corn. The complexity of choosing a productive rotation greatly increases when factors such as this are considered. More information about phytotoxins is contained in Martin and Touchton (1983).

All of these remedial cropping measures provide significant erosion control from surface runoff, and the increase in organic matter production can improve the soil structure and stability, possibly alleviating compaction, increasing infiltration which reduces runoff, and further reduces erosion. The effectiveness of cropping systems in alleviating compaction and the associated reduction in erosion is discussed in the section Compaction Control.

Other cropping practices that can be utilized in the reduction of soil erosion include contour strip cropping and buffer strip cropping. Contour strip cropping is a practice in which contoured strips of sod are alternated with equal-width strips of row crops or small grains. This practice is more effective than contouring alone. The seeding of eroded areas to perennial grasses and legumes is called buffer strip cropping. It is less effective than contour strip cropping (Wischmeier and Smith 1978).

2.4.4 TILLAGE SYSTEMS

The tilling of soil, conventionally, has several purposes, including:

- weed control
- control soil-borne insect pests and diseases
- incorporate pesticides and amendments
- loosen compacted soil to improve aeration and water infiltration
- decreases aggregate size to prepare a favourable seedbed and rootbed
- dry and warm the soil
- manage residue

Although conventional tillage systems are usually quite successful to achieve these ends, they have their drawbacks, the most important to this study is increased soil erosion. The type, frequency, and timing of tillage operations influence porosity, roughness, cloddiness, compaction, and microtopography. Tillage also affects water intake, surface storage, runoff velocity, and soil detachability, all of which are factors in potential erosion (Wischmeier and Smith 1978).

The oxidation of the soil reduces the organic matter content and impedes the particle bonding of microorganisms, and a decline in the aggregate stability ensues. Bulk density increases and soil porosity decreases, restricting aeration and water movement. Root growth is retarded and surface runoff is promoted. The impacts of compaction and nutrient deficiency, and their remedial measure are discussed in later sections.

Most tillage operations reduce ground cover, particularly crop residue, and increases the exposure of soil to the erosive elements. Residue is often more important in controlling soil erosion than vegetation cover. Residue may cover less surface area than a closed canopy cover but, because it is lower to the ground, it is more efficient in absorbing rain energy and it persists as a protective cover for a greater portion of the year (Wischmeier and Smith 1978). The type of tillage system determines the amount of the residue left on the soil surface.

The quantity of residue left on the surface is the dominant factor in the effectiveness in reducing soil erosion. Residue breaks the surface flow of water reducing its erosive power. It increases the retention time of surface water thereby increasing infiltration. Increases in the organic matter content near the soil surface improve the soil structure and natural drainage which in turn, increases the infiltration rate (Frye et al. 1985). Residue provides a protective cover for the soil in early spring when the soil is most susceptible to erosion. It also retains snow in the winter altering the freeze-thaw processes and spring meltwater conditions. There are many forms of tillage systems utilized in southwestern Ontario, the most common of which is the conventional tillage system. Convention tillage is the most intensive tillage system and includes primary and secondary tillage, followed by planting. Primary tillage in conventional systems consists of fall moldboard plowing. Secondary tillage includes spring disking (once or twice) and/or spring tooth cultivation (once or twice). Because conventional tillage is the most intensive it is also potentially the most degrading to the soil.

Narrow row crops, such as wheat and barley, allow no post-plant cultivation. Meadow crops are usually perennial and are not maintained with tillage. Row crops, such as corn and beans, require the most intense tillage and suffer the greatest soil losses from its effects. "There is a universal conviction among agricultural researchers that intense tillage, as it is practised today (conventional), is the main cause of erosion" (Hoechst 1984). This would suggest that the best way to control soil erosion would be to utilize less intense forms of tillage on crops or include crops that require less intense tillage.

Alternate forms of tillage that reduce soil erosion are collectively called conservation tillage. Conservation tillage includes reduced tillage, strip tillage, ridge tillage, minimum tillage, and no-till or zero-till. All forms of conservation tillage reduce the intensity of tillage practices and/or change the timing of tillage in comparison to conventional tillage practices for the purpose of reducing

soil erosion by increasing the amount of residue left on the surface, especially at critical times of the year. The effectiveness of these tillage practices in controlling soil erosion and their impact on productivity vary with soil texture.

No-till is the most extreme form of conservation tillage. The only tillage required is in the actual placement of the seeds during planting. No-till requires less traffic in the spring when the soil is most susceptible to erosion. The maximum amount of residue is left on the soil surface and the maximum erosion control is achieved. The increased bearing capacity of untilled soil allows the surface to be trafficked in wetter conditions. This can be especially important in late fall harvests when heavier machinery is used and the soil is high in moisture content. A complete discussion of no-till and the other forms of conservation tillage can be found in (Hayes 1982, Young 1982).

There has been extensive research undertaken to evaluate these tillage practices under various conditions. Most of the data on the impact of tillage on erosion in Ontario has been obtained from runoff plots at the University of Guelph. A series of ten plots has been in operation since 1952 and has been used to measure the effects of different management systems. Ketcheson and Webber (1978) reported that, over a six-year period, continuous no-till corn with stover left reduced soil loss to less than 0.01 cm/yr. By comparison, the greatest losses occurred when stover was removed and plots plowed in the fall. No-till markedly reduced erosion although it did not reduce runoff to the same extent. Although conservation tillage has been shown in these and other studies to effectively control erosion on uniform slopes, Battison et al. (1987) found much more severe erosion on the shoulder slope positions. Essentially no data are available on the effectiveness of remedial measures in controlling erosion on these slope positions.

A large proportion of the tillage research done in Ontario has been with corn on medium and fine textured soils. Vyn, Daynard and Ketcheson (1979 and 1982) focussed research on long term tillage experiments for corn production on four soil types, sandy loam, loam, silt loam and clay loam. Yields with zero tillage in these studies have averaged about 15% lower than those with conventional tillage when corn followed corn in rotation. When corn followed crops other than corn, yields were not as drastically reduced (Vyn, Daynard and Ketcheson 1979 and 1982). Subsequent research suggests that yields with no-till may be improved when discs or blades are used on the planter to remove residue from the row area. Researchers have noted that spring rather than fall plowing, may be an effective method of controlling erosion during this critical period (Vyn, Daynard, Ketcheson and Lee 1982, Miller 1984). Crop research has demonstrated, however, that, on finer textured soils, fall plowing is necessary to produce a suitable seedbed (Vyn, Daynard and Ketcheson 1982). The same research has also demonstrated that, on fine textured soils, there was no yield advantage related to excessive secondary tillage if soils were sufficiently dry at the time of tillage.

Many studies have been conducted, throughout the United States, involving various tillage systems on various soil types. Included in a special conservation tillage edition of the Journal of Soil and Water Conservation in 1983 are studies by Mannering and Fenster, Moldenhauer et al., Cosper, and others. This journal issue contains papers on many aspects of conservation tillage. Allmaras et al. (1985) summarize several other studies on conservation tillage.

Studies of tillage-planting systems in Ohio have documented the relationship between soils, tillage systems, crop yields, and soil erosion (Allmaras et al. 1985). Van Doren et al. (1976) showed that differences in corn yield with conventional and no-till systems were affected by soil type, immediate past cropping history/tillage intensity, and time. In the Ohio studies three cropping systems were used; continuous corn, corn-soybeans in a two-year rotation and corn-oats(seeded to alfalfa)-meadow in a three-year rotation. Various tillage techniques, ranging from moldboard plowing to no-till, were employed and tests were conducted on both fine and medium textured soils (Van Doren et al. 1976, Dick et al. 1986).

On fine-textured soils, corn yields were found to be consistently lower over a 22-year period where no-till was applied to a continuous corn cropping system. Yields were also reduced with a combination of reduced tillage and continuous corn. In rotations involving soybeans and oats, yields were slightly lower with no-till. It was found however, that most of the reduced corn yield could be recouped if either crop rotation or tillage were applied. Researchers also found that after 19 growing seasons, both tillage and rotation showed a significant effect on soil fertility (Dick et al. 1986). No till plots were found to be lower in pH but enriched in organic matter and plant nutrients in the upper 7.5 cm. Conversely they contained lower concentrations in the lower portions of the plow layer. These differences were attributed to the broadcast application of fertilizer without mechanical incorporation. Researchers did not attribute yield variation to the observed stratification of nutrients.

Research on medium textured soils in Ohio has been summarized by Van Doren et al. (1976). With regard to crop rotation it was found that lowest yields of corn were associated with continuous corn and the highest with a three-year rotation of corn-oats-meadow (Van Doren et al. 1976). During the initial six years of this study, 40% of all

no-till plots experienced problems with yield and weed control. Over the remainder of the study this "problem rate" was halved indicating significant progress in no-till technology. Generally, it was found by Van Doren et al. (1976) that corn yields on medium textured soils were relatively insensitive to tillage over a range of soil types, climate, cropping system and past history so long as equal plant densities and adequate weed control had been achieved. Selected no-till sites were observed to have suffered substantial yield losses on poorly drained soils but only when in continuous corn (Van Doren et al. 1976). Finally, some situations of improved yield with no-till were observed. These occurred on well drained sloping soils and were associated with conservation of moisture and improved soil structure. Allmaras et al. (1985) summarizes other studies conducted in Indiana and Illinois. Findings are similar to the Ohio studies just discussed, and will not be examined further. Included among their findings were the trend for poorer yields for no-till corn on poorly drained fine textured soils and equal or improved yield for no-till corn on medium textured, well drained soils. These same trends were evident for two-year rotations including soybeans but yield reductions were less dramatic (Allmaras et al. 1985).

Under the conservation tillage system, many of the objectives of tillage identified at the outset have to be met through other management practices. The most significant in southwestern Ontario is an enhanced pesticide programme. Management systems become more complex. New equipment has to be developed and old equipment has to be modified to deal with the changes in tillage. One of the most significant changes is in planting equipment. It has to be able to plant into large quantities of residue and it has to able to effectively apply fertilizer. Erbach et al. (1983) and Murphy (1983) discuss many of the technological developments associated with conservation tillage systems. The success of conservation tillage is dependent upon the effectiveness and acceptability of these changes. Apart from the effectiveness of conservation tillage in reducing soil erosion, Hoechst (1984) and Crossman (1981) identify other benefits which make it more acceptable than conventional tillage. They include:

- reduced labour
- redistribution of labour
- reduced equipment maintenance and cost
- reduced fuel use
- maintenance of optimum organic matter content in the soil
- declines in some weed populations
- greater moisture retention

Both authors discuss these benefits in comprehensive detail. Hoechst cautions that all of these benefits will not be seen under all conditions. There are other tillage practices that may be effective in controlling erosion without drastically changing cropping and tillage systems. Contour tillage, by increasing the cross-slope surface roughness, will retain surface flow and promote infiltration. Contour tillage does not lead to the concentration of flow downslope as does tillage with the grade. Researchers have concluded that surface residue cover is a more effective erosion control measure than surface roughness (Vyn, Daynard and Ketcheson 1982, Vyn, Daynard, Ketcheson and Lee 1982). The acceptability of contour tillage in southwestern Ontario as noted above, is limited by the often complex topography in the region.

An extensive on-farm research-demonstration programme, called Tillage-2000, is being conducted jointly by OMAF and the Dept. of Land Resource Science at the University of Guelph. The goal of the programme is to develop and evaluate conservation farming systems for specific soil types, which maximize economic productivity and minimize soil degradation. This study is more comprehensive than previous studies in Ontario because it goes beyond tillage systems; it is looking at the integration of conservation tillage practices with other conservation practices. Tillage-2000 was initiated in 1985 and now consists of 31 farm cooperators. Each study site has two treatments, a conservation and conventional tillage system. Paired permanent benchmark plots have been established for collection of data from each tillage system. Each of the permanent benchmark locations will be characterized with respect to topographic and soil properties. In addition to the one time detailed soil and topographic measurements, soil and crop data are collected each year from each benchmark. Measurements include crop yield, crop growth characteristics, emergence and population counts, surface residue cover, weed counts, soil fertility, pest and disease observations. For each treatment, information regarding most aspects of operation are recorded. These include type and use of equipment, estimated fuel consumption, herbicides, pesticides, seeding rates and date, fertilizer, and growing season rainfall. Soil erosion is measured with 137-cesium tracer which was discussed in the section entitled Measurement and Prediction.

Data has been collected for only one growing season and specific recommendations cannot be made. However, preliminary analyses indicate the conservation system was very successful. The average yield indices (conservation yield/conventional yield) were 1.0, 0.97 and 0.95 for sites with coarse, medium and fine textured soils respectfully. Economic analysis indicated a significant savings in time and cost per bushel for the conservation systems (Aspinall, et al. 1987).

A number of more detailed studies are also being carried out in Tillage-2000. These include nitrogen response of

corn under conventional and no-till systems and herbicide studies. Results of these studies are also preliminary.

A project similar to Tillage-2000 has been carried out for the last six years in Saskatchewan and is called Innovative Acres (Farm Lab project, Rennie et al. 1982). This project is administered by the Dept. of Soil Science, at the University of Saskatchewan. The objectives of this project are to maintain soil quality and productivity by developing water efficient farming practices. The emphasis on crop water-use is related to the dryland farming conditions in Saskatchewan. The programme utilizes the same concept as Tillage-2000 with paired farming systems being established on forty farm cooperator sites. Paired benchmarks were used within each farm site similar to Tillage- 2000. The goal with the Innovative Acres, as with Tillage-2000, is to bridge the gap between intensive plot-scale research and field application of the developed technology. Farming systems, not specific treatments are evaluated.

2.4.5 COMPACTION CONTROL

Soil compaction is the result of deterioration of the soil's natural structure and stability. It is a major form of soil degradation, often resulting in loss of soil and productivity.

The increase in soil bulk density and the decrease in macropore space associated with compaction are responsible for the reduction in oxygen diffusion and water infiltration, and the retardation of root development. The reduction in infiltration results in increased surface flow which in turn increases soil erosion. Soil compaction ultimately results in the reduction of the soil's productivity.

In a regional study of Canada by Rennie (1985), the annual profit lost in Ontario due to compaction was estimated at 21 million dollars (erosion = $68 million/annum) as compared to Quebec which had an estimated annual loss in profit of 100 million dollars (erosion = $10 million/annum). Rennie did not state how much of the losses due to erosion were compaction induced. Although the greatest contribution to Ontario's compaction related loss in profit is expected to come from Eastern Ontario, soil compaction in southwestern Ontario is no doubt a problem and definitely deserves consideration.

The significance of soil compaction in southwestern Ontario has not been well established. It is often overshadowed by the more obvious forms of soil degradation related to soil erosion. Wall et al. (1985) noted the great variation in the awareness of farmers in eleven counties in southwestern Ontario to soil compaction. In some counties the awareness was as high as 69% (Essex) whereas in most of the eleven counties less than forty percent were aware of soil compaction problems. The perceived significance of the problem was not determined. Soil compaction is clearly not recognized as a major problem in southwestern Ontario. This accounts for the lack of research into soil compaction, its effects, and its relationship with soil erosion.

The potential problem of soil compaction in southwestern Ontario, particularly with regards to soil erosion, has been realized by researchers but an assessment of the problem has not been available to date. Bolton et al. (1979) found that the practices involved in a continuous corn cropping system in southwestern Ontario had a detrimental effect on both the total and air-filled pore space, causing compaction. The promotion of erosion was not evaluated but compaction was responsible for reducing the uptake of nutrients. The processes and mechanics of soil compaction in south western Ontario are not fully understood. Without this understanding an evaluation of the problem is not possible, and proper remedial measures can not be taken.

Research has been initiated but it still remains in its preliminary stage. McBride at the University of Guelph is conducting laboratory studies on the mechanics of compaction and Vyn (Guelph), as well as Baldwin (Ridgetown) are conducting field studies on compaction. Kennedy, a Soils and Crops Specialist with OMAF, is looking at the problem of compaction on the flat, fine textured soils of the Stratford area in Perth county.

The greatest volume of research on compaction, its degrading influence on soil, its relationship to soil erosion, and remedial measures, pertinent to southwestern Ontario comes from the Great Lakes states. Prominent American researchers include Voorhees, Lindstrom, and Dickey.

Soil compaction is caused by the reduction in the soil organic matter content and/or the mechanical pulverization and compaction associated with management practices. Apart from the influence of cropping systems on organic matter input, tillage is generally responsible for changes in the quantity and quality of the soil organic matter content. It oxidizes the soil, decomposing the organic matter (Voorhees 1979). A decrease in organic matter and microbial activity results in instability, poor aggregation of the soil structure, and lower AWHC. The bearing strength of the soil is reduced. When the load of machinery exceeds the bearing capacity of the soil, compaction occurs. Tillage is also responsible for the pulverization of the soil structure. Operations, and high axle loads during harvesting, manure application are prime offenders,

particularly in situations where soil has a high moisture content.

Subsurface compaction is caused by forces that extend deeper than those of surface compaction. This deep compaction is induced by driving on or tilling a soil that is too wet with heavy equipment. Field studies done in Minnesota show that axle loads of between 10 and 20 tons compacted a clay loam soil to a depth of one metre (Anon. 1985). Typical tractor weights are about 20 tons (Voorhees 1986b). Harvesting equipment exceeds 20 tons per axle (Dickey et al. 1985a).

The degree of compaction is dependent upon soil type. Fine textured soils retain a high moisture content for a relatively longer portion of the tillage season and are therefore a greater concern than coarser soils. The weaker structure of fine soils makes them more susceptible to mechanical compaction (Dickey et al. 1985a, Voorhees 1986a). For these reasons soil compaction is a more prevalent problem on flat, fine textured soils such as those found in Kent, Essex and Perth counties. Coarser textured soils are not free from compaction but more obvious degradation due to erosion, related to their typical geomorphology (complex topography of glacial deposits), dominates.

Natural forces that expand and contract the soil work to alleviate compaction. Freeze-thaw processes and the wetting-drying of clay loosen the soil. These processes are slow and their effectiveness is determined by the extent of the process, their depth, and the number of cycles. Fracturing and aggregation of the soil can be caused by root growth. The stability of the improved state is governed by the organic matter. Research by Voorhees (1983) indicates that these processes may be limited below depths of 20 cm. Research in Minnesota showed that freezing and thawing broke up only half the compaction in the upper 8 cm of the soil and less than one quarter of the compaction in the upper 30 cm. Freezing and thawing, therefore, is generally considered ineffective at reducing subsurface compaction (Dickey et al. 1985). There is some evidence from the University of Guelph that frost action may only temporarily alleviate compaction. Soil was found to quickly reconsolidate upon thawing and return to near pre-freezing bulk densities prior to spring planting (Kay et al. 1985). Where natural alleviating forces are insufficient, remedial measures must be taken to control compaction and reduce soil erosion.

Remedial cropping and tillage practices are considered effective in controlling compaction. Choosing crops that require less intense tillage, particularly at critical times of the year, can be effective in reducing compaction. Whether or not reduced tillage systems reduce traffic is questionable because they require increased pest management, but the traffic is displaced from the spring period.

Voorhees studies cited in this paper point out a very important factor when considering changes to existing management practices. If tillage is reduced, not only are many of the compactive activities eliminated, most if not all the practices that alleviate compaction are eliminated. If natural forces are insufficient in alleviating compaction, reduced tillage systems may actually increase compaction, and soil erosion.

Voorhees and Lindstrom (1983) have questioned the effectiveness of reduced tillage in controlling compaction. Because the first pass over the field in multiple pass systems accounts for 75 to 90 percent of compaction, reducing the number of tillage passes has a minimal effect. Secondary tillage does not account for a significant portion of the total compaction. No-till reduces the amount of wetting-drying cycles, therefore it also is considered to have a limited effect because it lacks the alleviating forces of tillage and nature.

Tillage, although it causes compaction, also acts as a corrective measure to alleviate it. The effect tillage has with regards to compaction depends upon the soil water content, the soil type, and the kind of tillage operation (Voorhees 1983).

Reduced tillage systems because of their shallower depth and less intense disturbance were essentially no more effective in reducing penetrometer resistance or bulk density than natural forces (Voorhees, 1983). Voorhees (1983) cited Lindstrom, 1981, who, based on high penetrometer resistance and bulk density, stated that no-till soils may have significantly lower infiltration rates which could eventually result in runoff problems in the spring even though it does provide soil erosion control. But in a no-till system, the extensive network of biopores give much greater infiltration than is normally expected for a given bulk density and penetrometer resistance (1983).

Deep cultivation with plows or subsoilers can remedy the compaction problem. This practice may be common in the United States but in southwestern Ontario it is not. The success of deep cultivation is highly variable.

Varying the depth of tillage from year to year will impede the development of a compacted layer. Any tillage system, including no-till, can lead to the formation of a compacted layer if it is performed at the same depth year after year (Dickey et al. 1985b).

Voorhees (1983) reported that soil compaction caused by wheel traffic during the growing season can be alleviated to varying degrees by natural forces and autumn plowing.

In his research Voorhees observed a 50 percent reduction in the penetrometer resistance in the tilled layer of a compacted soil from natural weathering forces. The value of 50 percent was dependent upon the soil water content, higher moisture content results in greater frost action. Moldboard plowing together with natural forces decreased both the penetrometer resistance and the bulk density of the tilled layer of the compacted soil to essentially the same level as an untrafficked soil. Controlling traffic is an effective measure for controlling compaction. Permanent traffic lanes can be established to limit the amount of compacted area. Under conventional tillage systems as much as 90% of a field may be driven on at least once a year (Dickey et al. 1985). Because the first pass over the field results in approximately 80 percent of the total compaction, restricting all subsequent passes to those of the first field operation also reduces the total compaction (Voorhees and Hendricks 1977). Implement sizes have to be matched so that all wheel tracks are in the same inter-row space year after year. This may result in unacceptable costs. However, traffic control can reduce energy costs. The energy requirements on a compacted soil are less than a loose soil because there is less rolling resistance and more traction (Voorhees and Hendricks 1977). The acceptability of this practice is very limited because of its increased management restraints. In an attempt to reduce the number of passes over a field, many functions may be instrumented at one time but greater sizes of machinery are required. Larger machinery means greater loading on the soil increasing the compaction per pass. The size of machinery required for a no-till system is generally less than a conventional system because many of the heavier practices are eliminated. Reducing axle weight decreases the compactive force but reducing machinery size often means reducing efficiency and increasing costs.

Dual wheels can be used to decrease the severity and depth of compaction, only if the extra floatation is not used to work soils that are too wet to work without it. The compaction with duals is spread over a larger area though the total amount of compaction does not change (Dickey et al. 1985b).

Headlands are the most heavily trafficked portion of a field. Severe compaction and erosion can sometimes occur these areas making them unproductive. If this is the case headlands may be best left untilled and possibly under a permanent cover crop. This would reduce compaction and control erosion without greatly affecting their profitability.

Practices that return high quantities of organic matter to the soil are beneficial to the soil structure. Certain crops, such as alfalfa, included into rotation have been found to increase the bearing capacity of the soil and alleviate compaction because of their extensive root growth and high organic return (Angers et al., 1987).

Where compaction can not be controlled, measures can be taken to offset its effects such as artificially improving the drainage. These measures are examined in section 2.4.2, entitled Flow Control.

Voorhees (1979) has put the necessity of alleviating compaction into some doubt by demonstrating that compaction does have some benefits in reducing erosion and increasing productivity. Voorhees has suggested that soil compaction offsets the effects of decreasing organic matter on aggregate stability. The cloudiness of tilled compacted soil may reduce runoff and increase infiltration. Compaction will provide less erosion control on light texture soils where clods do not develop (Voorhees 1977a). Compaction may also improve the soil moisture condition in a dry season by decreasing evaporation and increasing capillary action transport (Voorhees 1977a). Voorhees does acknowledge the bad effects of compaction discussed in this review and states that wheel-induced compaction may do more harm than good (Voorhees,1977a, Voorhees 1977b, Voorhees and Hendricks 1977).

2.4.6 AMENDMENTS

Amendments to soils in southwestern Ontario are usually in the form of fertilizers or organic matter. They are applied to overcome detrimental effects of soil erosion, two of which are the loss of available nutrients and loss of organic matter content. Amendable nutrient deficiencies commonly associated with soil loss are N, P, K, and Zn (Batchelder and Jones 1972). The organic matter content can be increased with the addition of manure or the return of crop residue. Both of these effects of soil erosion ultimately reduce the productivity of the soil which make their remedy an economic concern.

Batchelder and Jones (1972) examined the ability of amendments to improve the productivity of eroded soils by increasing available nutrients and increasing the AWHC. To simulate severe erosion conditions on very fine sandy loam and clay loam soils of North Dakota, they stripped off the topsoil exposing the subsoil. They were able to directly compare the influence of fertilizers and mulch amendments on similar 'eroded' and non-eroded soils. Amendments to the subsoil were found to equal or improve productivity in relation to the unaided topsoil. Crosson and Stout (1983) have noted similar studies conducted in southwestern Iowa on Marshall and Monona silt loam soil. The conclusions of such research indicate that amendments to eroded soils can improve crop yields to at least equal to those of non-eroded soils when nutrient deficiency was the only limiting factor.

The problem with these studies is that the 'non-eroded' soils are not at their optimum productivity and therefore should not be directly compared to amended eroded soils. All soils under cultivation require amendments of varying degrees to sustain a high level of productivity. Olson (1977) found where equal amounts of fertilizer (N, P_2O_5, K_2O, Zn) were added to a Beadle silty clay loam typical of many glacial till soils in eastern South Dakota and western Minnesota that the non-eroded soil had higher corn yields. On an average of the six treatments over eight years, yields on the undisturbed soil were 37 percent above yields on the eroded soils. Fertilizer compensated for some but not all of the yield decrease incurred by topsoil removal. Olsen concluded that simply adding nutrients to severely eroded soils may not restore the soils original productivity. Other factors, such as available water holding capacity, affect the productivity of soils (Battiston et al. 1987).

Results from erosion studies by Frye et al. (1982) on two Kentucky soils also suggest that neither low-intensity use, nor optimum fertilizer amendments can restore a strongly developed soil to its original production potential after it has been damaged by erosion. Although the productivity may be increased on eroded soils through management, the productivity of severely eroded soils may never be restored to their original non-eroded state. Frye et al. (1982) cite another study with similar findings. In general, amendments are not very effective in reducing soil erosion, they merely offset its effects. The application of organic matter, however, increases the organic matter content which promotes aggregation and infiltration, both reducing erosion (Olsen 1977). Increases in organic matter generally increase the total water-holding capacity of the soil as well as the water supplying capacity of the soil, but apparently does not increase available-water-holding capacity, except in sandy soils organic matter holds much of its water with tension too great to be available to plants (Frye et al. 1985).

Crosson and Stout (1983) cite a study where large quantities of organic matter were returned to the soil. Soil aggregation was increased 30 percent and bulk density was reduced from 1.3 to 1.1. grams per cubic centimetre. This appears very impressive but Crosson and Stout caution that although non-humic material can be increased over relatively short periods of time by returning crop residue to the soil, including leguminous forage crops into rotation and manuring, these non-humic materials rapidly decompose. It is the accumulation of humic material which has a strong influence on soil structure. This process is very slow.

Fertilizer amendments can indirectly improve the soil structure by increasing the amount of crop residue produced. A positive feedback relationship may be established.

Another consideration when applying fertilizer as an amendment is the differential erosion that exists within a field. This 'scattering' of erosional areas within a field poses problems for the treatment of nutrient deficiencies with fertilizer application. A uniform application of fertilizer will not be appropriate for all field areas. Technological advances into variable rate applications may result in the development of an acceptable system to deal with such situations.

Various industrial wastes, such as sugar lime, a by-product of sugar refining, may be effective amendments to reduce soil erosion. Some are currently being tested. The amounts of these available and the cost of transporting them may limit their usefulness to very restricted areas. Other chemicals, such as polyvinyl alcohol, are also very effective soil structure stabilizing agents. At present, the cost of such chemicals prohibits their use beyond research scale (Groenevelt et al. 1987).

2.4.7 Acceptability of Remedial Measures

The acceptability of remedial measures which are proven effective, from a soil conservation perspective, cannot be assumed as given. Assessments regarding the adoption of conservation tillage systems often presume incorrectly, that the resource conservation benefits are clearly evident (Allmaras et al. 1985). Swanson et al. (1986) contend that farmers generally opt to maximize short-run profits at the expense of land resource protection. Farmers in Canada and the United States have, over the past two decades, been forced to increase their scale of operation. "During the 1960 and 1970's the scale of agriculture increased because of market pressures, technological growth and relatively low interest rates" (Swanson et al. 1986). Many farmers throughout North America accepted heavy debt load during this expansionary period. Subsequent economic recession in both countries has left many farmers in financial difficulty. Earlier in this report the concept of "planning horizons" was introduced as part of a discussion of tolerable rates of soil loss. Over the past decade the economics of farming have not been conducive to lengthy planning horizons and thus have not been conducive to adopting soil erosion control practices. The reason for this is because returns on investment in conservation are generally held to be unrealized in the short term (Swanson et al. 1986). In Ontario, the economics of conservation technologies have been examined by Stonehouse et al. (Stonehouse, Baffoe, Kay and Johnston-Drury 1987, Stonehouse, Kay, Johnston-Drury and Vyn 1987). These researchers note that

monocultural corn and corn - soybean rotations have been much more profitable than traditional forage-based rotations. This profitability was based, however, on the long-term maintenance of yield levels despite the effects of soil erosion. While this may be possible on selected locations, evidence presented earlier in this review revealed that future yield reductions may frequently be expected with continued erosion despite current yield maintenance. Stonehouse, Baffoe, Kay and Johnston-Drury (1987) and Stonehouse, Kay, Johnston-Drury and Vyn (1987) examined anticipated levels of profit associated with various cropping and tillage scenarios. They also estimated attendant soil loss for each scenario using the Universal Soil Loss Equation. The farm-level economic picture was taken to include annual net returns (in 1987 dollars) plus the present value of the farm business net worth at the end of a four-year and twenty-year planning horizon. This study assumed a land base of 200 ha featuring medium textured soil and 7% slope. Stonehouse, Kay, Johnston-Drury and Vyn (1987) found that, in the short term, a crop sequence of corn-corn-soybeans-winter wheat yielded the highest return irrespective of tillage technique. Slightly higher net returns (1%) were associated with the use of conventional tillage over conservation tillage. This slight difference was found to be offset by a 20% reduction in soil loss with mulch tillage. Substantial soil erosion benefits were associated with a combination of no-till and mulch tillage in a corn-soybean rotation. However, such a system was accompanied by a 10% reduction in return and was therefore deemed unlikely to be adopted in a short term planning horizon. Other scenarios revealed a wide ranging set of costs and benefits using conventional tillage. The scenario which resulted in the lowest amount of soil erosion was also the least profitable. This would suggest that soil conserving measures are inherently expensive to farmers. While the total adoption of the most soil saving farming system may be cost prohibitive, this study suggested that significant soil conservation is available at marginal cost through the adoption of conservation tillage only (Swanson et al. 1986, Stonehouse, Kay, Johnston-Drury and Vyn 1987). The results of this study are limited to the parameters selected; however, it does provide an example of the type of economic analysis that is required by farmers for decision making. In the United States, the economics of soil conservation has been studied in Iowa. Pope et al. (1982)simulated 18 farms which as a group were representative of 1) the range of erosiveness existing in the state 2) each of the soil types in the state and 3) the major land resource areas in the state. A large number of scenarios were constructed by selecting various options within three categories; crop rotations, tillage system and supporting practices. Linear programming models were used to assess economic returns to land, labour and management on each scenario for each of the representative farms. Data requirements of the linear programming models are very large and this study should be consulted for information on methodology and the individual coefficients.

The model, when applied, examined economically optional levels of soil loss from the perspective of the individual farmer. A range of cropping systems that resulted in various levels of soil loss and net return was presented. Although the results of this study cannot be fully recounted in this review, it was shown that a reduction in soil loss from the 1985 rates could be achieved without reducing associated net returns. It was also concluded that cropping systems which yield higher current net returns at the expense of eroded soil, may prove less profitable in subsequent years than other soil conserving systems. The fundamental conclusion of this study, vis-a-vis Ontario, was that economically tolerable amounts of soil loss decline rapidly as planning horizons extend.

Swanson et al. (1986) have examined how the individual characteristics of farmers contribute to the adoption of soil conservation practices. They have been placed in three broad categories; source of information, personal characteristics and farm structure factors. Source of information implies the power of innovation diffusion and suggests that technology transfer is a key element of adoption. Personal characteristics have been examined by mainly researchers in the United States (Pope et al. 1982, Swanson et al. 1986). They contend that age, sex, education etc. impact on adoption behaviour with younger farmers generally more receptive to innovation. This notion is based on the study of learning theory and the adult learning process. Generalization is obviously involved in such statements (Pope et al. 1982).

Farm structure factors relate to economic or managerial "realities" that prevent farmers from behaving in ways that are consistent with their attitudes (Swanson et al. 1986). Farmers who accept the merit of conservation technology on environmental grounds may be prevented from adoption because of short run cost or managerial complexity. Additionally, farmers under heavy debt load may be unwilling to accept the perceived risks and uncertainties of new technology (Swanson et al. 1986, Pope et al. 1982). Clearly, the matter of socio-economic barriers to the adoption of conservation technology is as complex as the technology itself. Much literature is available, particularly from the United States, which examines the many economic and sociological forces affecting the implementation of remedial measures to control soil erosion. These include demographics, land tenure, institutional arrangements and many others. While this topic is of obvious importance to the full consideration of soil erosion in Ontario, it is thought to be beyond the scope of this review.

3. Reducing Phosphorus Input to Surface Waters

Nonpoint sources of pollution in both the Canadian and American Great Lakes Basin have long been recognized as key contributors to the declining quality of surface waters in these regions (Wall et al. 1982, International Joint Commission 1983). Erosion in the rural landscape has been recognized as a major cause of pollution in the Great Lakes (Wall et al. 1982). While sediment alone does not pose a serious threat to water quality, sediment particles carry various nutrients, heavy metals and pesticides which cause serious damage (Miller and Spires 1978). Among the most active contributors to increased rates of eutrophication is phosphorus (Wall et al. 1982, Miller et al. 1982). The reduction of phosphorus loadings to Lake Erie has been identified as one of the major objectives of the Soil and Water Environmental Enhancement Program. The phosphorus component of the SWEEP mandate calls for a reduction of phosphorus load from non-point agricultural cropland sources to Lake Erie by 200 tons per year by 1990.

The consequences of phosphorus loading to the Great Lakes include excessive algal growth causing the fouling of beaches, the clogging of water intake system and depletion of oxygen supply in deeper waters (Baker 1985). These have been well documented through the work of PLUARG (1978) and other agencies (Hore and McLean 1973) over the past fifteen years. The purpose of this section is to examine certain key issues relating to the movement of sediment and/or phosphorus, and the control of such movement, from farm field to stream. In-stream processes, although significant to final delivery, are considered to be less amenable to remedial measures and consequently are not included in this review.

In consideration of the agricultural sources of phosphorus and the problem of excessive stream P loading, it is necessary to examine the types of available P, its agricultural practice-related origins, the physical processes responsible for transport and delivery and the extent and distribution of the problem in Southern Ontario. Only through accounting for each of these elements of phosphorus loss from cropland can the identification of effective technologies and the proper spatial allocation of remedial measures occur.

The issue of phosphorus loss, like soil loss, is complicated by many physical and human variables and interdependencies. Among the most significant is the soil erosion process itself. During this review and discussion of phosphorus loading it is useful to identify linkages and commonalities with soil erosion. Awareness of such linkages facilitates the identification of areas where problem conditions co-exist, thus maximizing the environmental return to properly selected remedial measures. In addition to identifying opportunities to address both soil loss and phosphorus control objectives in concert, recognition of inter-relationships will also aid in the identification of measures which have potential to worsen one condition while treating the other. For example, the utilization of no-till technology may reduce soil erosion but leave increased amounts of phosphorus on the soil surface thus contributing to increased P yield. The following sub-sections review what is now known about various aspects of phosphorus loss and its control.

3.1 Measurement and Prediction

It is generally held that phosphorus loss occurs, at varying levels and on agricultural land in Southern Ontario. In order to identify key contributing areas and reduce loading from agricultural lands it is necessary to examine both the magnitude of present P loss and the likelihood of future P loss. Tools of measurement and prediction are required. As with soil erosion, direct measurement facilitates accurate analysis of problem conditions on site-specific levels. Predictive abilities contribute to efficient broadscale analysis and are essential to the development and implementation of non-point pollution control programs.

Stream phosphorus loads have been measured in Ontario. Sediment data monitored at watershed outlets are useful for validating predictions of phosphorus transport with sediment from cropland (Rosseau 1985). Unfortunately, relatively few rivers draining into the Great Lakes have stations where suspended load has been measured regularly (Dickinson and Wall 1977). Best results are achieved through regular and event-oriented monitoring of sediment-associated and dissolved P concentrations. Dickinson (1972) and Dickinson and Pall (1982) have shown that P loading varies temporally and is strongly related to major storm (i.e. runoff) events. Dickinson and Wall (1977) estimate that 80% of suspended material in Southern Ontario waterways is moved downstream in less than 10% of the time. These findings have been generally supported by studies conducted in Ohio and elsewhere. Sporadic monitoring, and monitoring patterns which may miss key events, do not provide accurate measures of stream P loads.

Measured P loads at the outlet of several representative Southern Ontario agricultural watersheds were used by Miller and Spires (1978) and Miller et al. (1982) to

develop regression equations which related stream P loads to the following watershed characteristics: average % clay and sand in surface soil; fertilizer P, manure P and total P added; % area in hay-pasture, alfalfa, row-crop, corn, woodlot or unimproved land; rural residences; and stream densities.

In this study, measured P load at the watershed outlet was used to develop predictive methods. Multiple regression analysis was applied to 11 agricultural watersheds and showed that two characteristics - % clay in surface soil and % area in rowcrop - were of primary importance in explaining the variability of total P loads, accounting for 85% of total P variability. Regression was also used to examine total dissolved P and watershed characteristics. In this analysis, % clay and total P added (fertilizer & manure) were found to be significant. Fertilizer and manure added was found to be the most significant in predicting dissolved P load. Predictions of stream P loads have also been produced through the estimation of contributions from individual agricultural sources. These sources were 1) runoff from cropland 2) runoff from livestock operations 3) runoff from unimproved land and 4) erosion of farm streambanks (Miller and Spires 1978, Miller et al. 1982). Runoff from cropland was found to be the major source of phosphorus from agricultural activities in the study watersheds. Estimates ranged from 50% to 92% with an average of 70%. Averaged contributions from livestock, unimproved land and farm streambanks were 20%, 3% and 7% respectively. In recognition of the importance of cropland runoff, it has been selected by SWEEP as a key target for remedial measures. Cropland runoff will be discussed more fully later in this section.

Miller and Spires (1978) attempted to validate regression equations by extrapolating total P load estimations to two larger watersheds (Saugeen and Grand) for which stream P at the outlet had been measured. It was found that loads from agricultural activities, estimated by regression, compared quite favourably with measured load. Base on the successful validation of this predictive method, the unit area load of total phosphorus from agricultural land in the subwatersheds in the Ontario portion of the Lower Great Lakes Basin was estimated by regression. Total P loading from agricultural activities was estimated to be 3,000 tonnes yr^{-1} with approximately 50% of this total P found in tributaries to Lake Erie (Miller et al. 1982). Subsequent mapping of load estimates revealed that the major contributing areas in southwestern Ontario were the level clay soils of Lambton, Kent and Essex counties (Miller et al. 1982). Although researchers endorsed these regression equations as a means of estimating stream P loads from agriculture they note that their reliability would be significantly improved with long-term measured data.

In the United States, agricultural nonpoint-source pollution monitoring programs have fallen into two general categories (Baker 1985); edge-of-field studies and regional water quality studies. In field level studies American researchers have collected water samples from rainfall simulations, research plots and individual fields. Baker (1985) notes that resulting data have most often been interpreted in terms of field rather than stream damage, and further notes that existing water quality models cannot extrapolate edge of field data to descriptions of regional water quality (Baker 1985, International Joint Commission 1983). American researchers have utilized methods, similar to those used by Miller et al. (1982) in Ontario, to produce regional water quality estimates. Baker (1985) echoes the concern of Ontario researchers regarding the need for regular long-term monitoring data in the development of reliable estimates of stream P loads.

A study conducted between 1974 and 1982 in northwestern Ohio on level, fine to medium textured soils found large annual variations in sediment loading and thus large variations in P loading. Rural non-point sources accounted for 51% of total P (Baker 1985). This study also examined the effectiveness of measures such as conservation tillage for the control of phosphorus from cropland. These findings will be discussed later in this report.

Researchers in the Ohio study found unit area P loads were nearly three times the national average from agricultural land while gross erosion rates were less than the national average (Baker 1985). This situation was attributed to the proliferation of rowcropping on soils with relatively high clay content. Such a conclusion is consistent with the findings of Miller and Spires (1978) in southwestern Ontario reported earlier.

While the research described in the preceding paragraphs was based primarily on measurement and monitoring, several mathematical models have been developed for predicting nonpoint water pollution. Two types of mathematical models are discussed by De Coursey (1985): they are empirical and physical process models. While empirical models such as regression and statistical time series analysis are generally well understood and relatively simple to apply, DeCoursey observes that they are "difficult to improve, difficult to extend beyond the range of data used in their development, are easily misapplied and can be misleading about cause and effect" (De Coursey 1985).

Physical process models have been used to predict responses and assess effects of various environmental conditions (scenarios). Unfortunately, process models are generally thought to require very high data inputs to develop and extensive research to validate. Most relevant

to our examination of stream P loading has been the development of several surface runoff models capable of simulating the movement of water and pollutants over and through the soil to stream channels.

The most notable of these are well summarized by De Coursey (1985) in the Journal of Soil and Water Conservation. The following brief description of these models is largely taken from this article. Specific references for each are provided for those wishing detailed information.

The Hydrologic Simulation Program Fortran model (Johanson et al. 1980) simulates the movement of dissolved oxygen, organic matter, temperature, pesticides, nutrients, salts, bacteria, pH, sediment and plankton from the land surface through stream systems. This model, while comprehensive, requires enormous quantities of data based on many years of record. Difficulties relating to the availability of such data in Canada have already been noted.

A less detailed runoff model has been developed at Purdue University in Indiana. The Areal Nonpoint source watershed environment Response Simulation (ANSWERS) (Beasley et al. 1980) is a physically based model that can be used to study the effect of land management on soil erosion and sediment yield. ANSWERS has been used by Beasley et al. (1980) to assess the impacts of conservation tillage on the movement of sediment and phosphorus from the midwestern Lake Erie Basin (Ohio, Indiana, Michigan). The model was used with a P transport relationship for simulation purposes. Only one model has been developed in the U.S which specifically simulates the response of field-sized areas. The Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS) (Knisel 1980) model consists of several options to simulate tillage, crop growth, erosion, sediment yield and plant nutrient movements. This model has been used extensively in the U.S. on field scale research and is presently being revised in order to expand its assessment capabilities. Several other models have been developed throughout the United States which examine erosion and associated sediment yield at varying levels. These are too numerous to include in this report.

Physical process models have been developed and successfully utilized in Ontario. The Guelph model for evaluating the effects of Agricultural Management Systems on Erosion and Sedimentation (GAMES) has been developed by Cook et al. (1985) at the University of Guelph. GAMES, estimates seasonal and spatial erosion losses and subsequent delivery of sediment at the outlet of small agricultural watersheds. The model accommodates combinations of spatial land units of any size and shape and is able to utilize seasonal time frames to reflect changes in soil erodibility, cropping and climatic conditions. The Universal Soil Loss Equation and a delivery ratio function are used in GAMES to account for soil loss and delivery to stream (Dickinson and Pall 1982).

The GAMES model has been used by Dickinson and Pall (1982) to examine soil loss/delivery and to evaluate a variety of agricultural management scenarios in several southwestern Ontario subwatersheds. Regarding erosion and delivery they found that in an upland watershed, 62% of spring sediment load originated from 15% of the watershed. Conversely, examination of a lowland watershed revealed that sediment yield was much more uniform. Proximity to stream was found to strongly influence sediment yield on both sloping and level fallow land. On sloping land, primary reasons were high rates of erosion. High delivery ratios accounted for increased yield on level land. As distance from stream increased, steeply-sloped row-crop areas were found to contribute little if any sediment regardless of in-field erosion rates (Dickinson and Pall 1982). The findings of Dickinson and Pall (1982) regarding potential impact of management practices are summarized below:

- Soil erosion and sediment yield reductions did not necessarily occur in concert.
- Crop rotations and surface residue management were predicted to potentially reduce soil loss by 50% to 75%.
- Only minor reductions in sediment yield accompanied measures intended to reduce soil loss. Specific field level measures such as strip-cropping and buffer strip have been observed to produce significantly greater reductions in sediment yield than in soil loss.

Researchers concluded that it was necessary to differentiate between rolling upland and level lowland watersheds when assessing soil erosion and sediment yield. Upland watersheds were found to exhibit localized erosion which, if controlled, would significantly reduce sediment loads. These areas of erosion are most often situated in close proximity to surface water (natural or drainage ditch). It should be noted that they may not necessarily correspond with the areas of erosion resulting in crop yield reduction which were discussed earlier in this report. The existence of localized erosion suggests the possibility of identifying and focusing on key contributing areas in the delivery of remedial programs. In lowland watersheds, given the expansive nature of relatively low rates of erosion, it was not possible to identify discrete contributing areas; consequently the application of widespread control measures would be required in order to significantly reduce sediment/phosphorus yield. These findings are of key importance to the allocation of tolerable rates of P loss, discussed in the next section. Recently, the GAMES model has been slightly modified

to specifically account for phosphorus loss (Rousseau 1985). This revised version of GAMES estimates the total phosphorus concentration of surface soil, potential soil loss, field to stream sediment yield and field to stream phosphorus enrichment. This model has been utilized in a study of a subwatershed of the Avon River in Perth County (Rousseau 1985). Application of this model revealed that the spatial variability of P yield corresponded with the variability of sediment yield.

In this study, conducted on rolling topography, most sediment and phosphorus loading was found to emanate from steeply sloped corn and grain fields located near drainage channels. These findings agree well with observations from upland applications of the original GAMES model noted earlier. Applications of the revised GAMES model for phosphorus are limited in number but appear to substantiate rather than refute the validity of existing process models.

3.2 Tolerable Phosphorus Loads

Over the past decade, both the scientific and political communities have debated tolerable phosphorus levels in the Great Lakes. Desired reduction levels for Lake Erie, the shallowest of the lakes, have been established and represent a key element of the SWEEP programs mandate. Given a specified tolerable phosphorus level at the lower limit of Erie Basin river systems, upstream locations must be examined to determine where, and in what manner, sufficient P loss reductions might be achieved. Two options would appear to exist for the allocation of tolerable P levels across the southwestern Ontario landscape. These are 1) uniformly applied rates across all areas or 2) the identification of specific areas (i.e. targeting) for intensive treatments. The concept of uniform application of phosphorus reductions suggests an equitable spatial distribution of available technical and financial assistance and also implies that farm level costs associated with reducing P loads will be evenly borne amongst southwestern Ontario farmers. Such an approach, while appearing equitable on social and political grounds, is unlikely to provide best results. As discussed earlier in this report, Miller et al. (1982) and Dickinson and Pall (1982) have shown that P loading is not uniform across the Southern Ontario landscape but varies both spatially and seasonally. The identification and treatment of priority areas recognizes the variability of sediment and phosphorus loss and attempts to achieve the greatest improvements in water quality for the minimum regional investment in revised management practices (Maas et al. 1985). The value of effective targeting has been well established for both erosion control and phosphorus load reductions in Canada and the United States (Lovejoy et al. 1986). A study conducted in Indiana, in 1982, examined the cost effectiveness of targeted and non-targeted erosion control programs (Lee et al. 1985). While specific findings varied with the simulated rate of adoption, it was demonstrated that in all cases, targeting increased cost effectiveness substantially.

If the merits of targeting are established and accepted it is necessary to consider the methods and options for selecting critical areas. The diverse topography, soil types and current management practices occurring in Southern Ontario suggest that the causes and processes of phosphorus loss are not uniform on broadscale levels but rather that they vary between and within regions.

Researchers in Canada and the United States have developed predictive methods, based on physical process models such as GAMES, CREAMS, ANSWERS etc., to construct and evaluate scenarios representing the various physical and cultural factors which influence P loading. Such predictive methods contribute to the assessment and comparison of a broad range of P allocation alternatives. As noted earlier in this report, best alternatives or scenarios will be those which maximize P reductions while minimizing cost and complexity and which also contribute to the achievement of soil erosion objectives. With reference to alternatives, it was noted in section 3.2 that upland watersheds are characterized by widely variable rates of P loss with high proportions emanating from a relatively small percentage of the landscape. Dickinson (unpublished data) has determined that up to 80% of P loading is produced from 20% of the area in rolling upland watersheds in southwestern Ontario. Selection of an upland scenario implies rigorous application of remedial measures to specific land units. Alternatively, Miller et al. (1982) have found that P loading from relatively level, fine textured soils, such as those found in Kent and Essex counties, is comparatively high. In contrast to upland areas researchers (unpublished data) observe that sediment and P transport is occurring over most of the landscape with excessive P loss attributable to the cumulative contribution of many land units. Selection of lowland targets thus implies the application of remedial measures over large areas.

Dickinson (unpublished data) notes that areas of excessive P loss in upland watersheds are usually associated with soil erosion. Such findings indicate the need to control soil loss in order to reduce P yield. Conversely, high P loadings in level lowland areas is largely attributable to very high delivery ratios and is not associated with excessive soil loss from the standpoint of productivity. These variations in causes of P loss represent important inputs to the development of representative scenarios for

the evaluation of spatial alternatives in the allocation of phosphorus load reductions.

Finally, little information could be found in the literature regarding similar allocation strategies in the United States. However, several researchers do stress the importance of recognizing the significance of dissolved bio-available P and recommend that emphasis be placed on the treatment of this form of P above any other consideration (Baker 1985, Sonzogni et al. 1982).

3.3 Areal Extent

Research conducted on eleven agricultural watersheds in southwestern Ontario formed the basis for an extrapolation of stream P loads to the Southern Ontario portion of the Great Lakes Basin (Miller and Spires 1978, Miller et al. 1982). Methods were discussed in section 3.1. This research produced values for contributions of phosphorus from agricultural sources at a broadscale level. While such information represents a valuable estimation of the areal extent of P loading, the researchers note that its reliability would be significantly improved with long term data from monitoring. Although the absolute values produced by regression analysis are limited by data, the research noted above does provide a reasonably reliable ranking of contributing areas.

Research by Miller et al. (1982) Miller and Spires (1978) and Wall et al. (1982) has examined the magnitude of sediment and phosphorus loss, independent of any consideration of tolerable loading. The allocation of tolerable P discussed in section 3.3 will provide a useful basis for comparison with actual loading to identify areas of excessive P loss. We suggest that the comparison of various allocation scenarios with estimated actual P loading will produce mappable illustrations of the areal extent of excessive stream P loading. Further comparison with regional soil loss mapping (Shelton et al. 1984) may reveal areas in which both SWEEP objectives might be addressed in concept.

3.4 Sources and Forms of Phosphorus

Phosphorus yield from agriculture has been studied with respect to the relative contributions of specific agricultural activities in southwestern Ontario. PLUARG researchers (Miller et al. 1982) have identified 4 major sources of phosphorus; 1) surface runoff from cropland 2) runoff from livestock operations 3) streambank erosion, and 4) runoff from unimproved land. Other sources were found to be significant in localized situations. These were drainage of organic soils, seepage from private septic systems and the addition of contaminants such as milkhouse wastes through illegal drain hookups.

In southwestern Ontario, cropland was found to be the most significant source of phosphorus accounting for an estimated 70% of stream loadings (Miller et al. 1982). Other sources were found to be less significant on average with livestock accounting for 20% of total P loading. The contribution from streambank erosion and unimproved agricultural land averaged 7% and 3% respectively. In recognition of the importance of cropland as a source of phosphorus, the SWEEP program has been designed to focus on this issue. Consequently, other sources will not receive further attention in this report.

Miller and Spires (1978) found that the proportion of particulate P to total P from cropland increased with increasing sediment concentration, and conversely that the proportion of dissolved reactive P to total P from cropland declined as sediment concentration increased. It was observed that dissolved P, the most bio-available form of phosphorus, was greatest from fields with fertilizer and/or manure on the surface. A model has been developed by PLUARG researchers which predicts sediment associated phosphorus yield (Miller et al. 1982). This relationship has been expressed as "Sediment P in cropland runoff = soil loss x P content in surface soil x P enrichment ratio x sediment delivery ratio".

As noted earlier in this report, research in Ontario (Miller et al. 1982) and in the United States (Baker 1985) has shown that most of the P entering Lake Erie is in particulate form. A study conducted by Baker (1985) in the western Erie Basin, of the United States, found that 80% of total P was in particulate form; 25% of which was bio-available. Conversely, of the remaining 20% in dissolved form, 90% was found to be bio-available. Such findings would appear to relate directly to the concept of tolerable loads and allocation alternatives discussed in section 3.3. Baker (1985) observed that the focusing of remedial measures on areas of high soil loss and sediment yield may reduce the quantity of relatively unavailable particulate P while increasing the quantity of highly bio-available dissolved P. The reasons for this will be clarified in a discussion of remedial measures presented later in this report.

Sonzogni et al. (1982) acknowledge that particulate P often represents a high proportion of the total P input to lakes and thus represents a major reservoir of P to organisms. Particulate P fractions can consist of organic, inorganic and condensed forms. The inorganic P fraction is the most significant as a source of bio-available P. Particulate inorganic P is further divided into nonapatite

and apatite fractions. Researchers have observed that apatite P is only slightly soluble in most natural waters and thus largely unavailable for plant uptake (Miller et al. 1982, Sonzogni et al. 1982).

As noted earlier, dissolved reactive or dissolved inorganic P is the directly bio-available form of phosphorus (Sonzogni et al. 1982). Other forms are available only through conversion to inorganic phosphate. Other forms of P in solution include dissolved condensed phosphates and dissolved organic P. The potential for these other forms of dissolved P to be converted to bio-available forms is significantly affected by

characteristics of the receiving water and the source from which the P was yielded. Sonzogni et al. (1982) have noted that waste water more rapidly converts non-available P to available forms. Similarly, they observed that dissolved organic P released from plant tissue and animal waste is converted rapidly to dissolved reactive P when released into streams, while that from soils is more stable and less susceptible to conversion.

3.5 Processes and Causes of P Yield in Cropland Runoff

Similar to the earlier discussion of the processes and causes of soil erosion, it is necessary to examine and understand these elements of the phosphorus loading problem. Knowledge of the processes and causes of P yield will form a basic input to the selection/development of effective remedial measures.

It is clear that particulate-P loading is governed by those processes affecting soil erosion. While the processes of detachment and transport are fairly well understood, stream P loading also requires the delivery of eroded sediment.

It is generally agreed that the concept of delivery ratio is critical to the identification of areas which are actually yielding excessive P to streams. Researchers note that movement within a field does not necessarily equal delivery (Dickinson and Pall 1982).

In Ontario, estimations of sediment loads have combined the Universal Soil Loss Equation and a specified delivery ratio. The USLE, its applications and limitations were discussed earlier in this report. Miller et al. (1982) and Wall et al. (1982) have used delivery ratio values provided by the Soil Conservation Service (1973) in the United States to produced estimates of P loading and sedimentation respectively. Researchers in Ontario and elsewhere have also attempted to utilize physical process models to better calculate delivery ratio (Dickinson and Pall 1982, Rousseau 1985). Models such as GAMES, CREAMS and ANSWERS offer potential to accurately determine field level delivery ratios by including specific information for location, topography, cropping and management etc. A search of relevant literature, however, suggests that little validation of these models has occurred at field level vis-a-vis the determination of delivery ratios. With reference to the validation of delivery ratios, the importance of re-examining the relationship between sediment source (erosion) and delivery must be emphasized. In the past, the final product, sediment load, has been measured and the source (erosion) estimated with the Universal Soil Loss Equation. These values have then been used to calculate a delivery ratio value. However, discussion of the USLE earlier in this report suggested that the validity of the predictive ability of the USLE in Ontario is, at best, questionable. Review of sediment source in the sedimentation equation inherently implies re-evaluation of delivery ratio as well.

Unlike sediment-associated P, dissolved P is transported via runoff and is independent of the soil erosion process, requiring only the delivery of water to the stream in order to contribute to loading. As discussed earlier in this section, dissolved reactive phosphorus is the most readily available for uptake by plants.

PLUARG researchers (Miller et al. 1982, Miller and Spires 1978) found that dissolved reactive P in eleven agricultural watersheds in southwestern Ontario, was greater from fields possessing high available P levels and in areas with manure on the soil surface. Dissolved reactive P in 10 samples of runoff from fields to which manure had been applied but not incorporated averaged 0.69 mg L^{-1}. Samples from 33 fields which contained no manure or in which manure had been incorporated averaged 0.098 mg L^{-1}. In addition to dissolved reactive P from manure and fertilizer added, Sonzogni et al. (1982) indicated that dead or dying vegetation may release significant quantities of bio-available phosphorus. Consequently, researchers have noted that dissolved P may also be relatively high in runoff from fields in perennial forage due to P released from dead vegetation.

Finally, as noted earlier, PLUARG researchers (Miller et al. 1982) and American scientists (Baker 1985) have observed that dissolved P represents a relatively small proportion of total P from agriculture under present management systems. However, the high bio-availability of this form of P makes it significantly more damaging per unit P than associated particulate forms. While much research has centred on the perceived need to control particulate P, we caution that land and program managers

must not adopt measures which will inadvertently increase the yield of highly bio-available dissolved reactive P.

3.6 Remedial Measures

Remedial measures to reduce phosphorus loading from cropland sources must recognize the basic elements of P yield which were identified in section 3.5. These are P content at the soil surface, soil loss, delivery ratio and P enrichment ratio (Miller et al. 1982). In order to reduce P loads, remedial measures must reduce one or more of these components without increasing other components proportionately. The following discussion addresses remedial measures as they relate to each of these key components of sediment associated P. As noted earlier sediment associated P has been found to be the dominant form of phosphorus entering Lake Erie (Miller et al. 1982).

3.6.1 Soil Loss

Available measures to control soil loss have been discussed in section 2.4. It was found that the two most promising general measures were cropping systems and conservation tillage. Researchers in Canada and the United States have examined the role of conservation tillage in preventing soil loss and associated P loading. Baker and Laflen (1983) state that the reduction in soil erosion possible with conservation tillage compared with conventional tillage is valuable from a water quality perspective based on associated reductions in sediment and nutrient losses. These researchers also contend that, in some cases, runoff can be lessened with conservation tillage thus reducing losses of soluble, non-adsorbed P. In other cases, however,the maintenance of crop residue on the soil surface limits fertilizer use options and may result in increased P concentrations which would negate the water quality benefit of reduced runoff (Baker and Laflen 1983). This will be discussed in section 3.6.3.

Romkens et al. (1973) observed that total P losses have been found to decrease, due to soil loss reductions, with conservation tillage systems. However, studies have also indicated that concentrations of dissolved P may substantially increase with conservation tillage (Andraski et al. 1985, Romkens et al. 1973). The implications of this relationship were discussed in section 3.5. Researchers have also found that, in some instances, available sediment P concentrations and losses have been greater for conservation tillage relative to conventional tillage (Andraski et al. 1985). The reasons given for this were the existence of unincorporated manure and a release of P from crop residues. While increases in P concentration of surface soil have been traced to conservation tillage, it is generally agreed that, in most cases, reduced soil loss will result in reduced total P but that the measurable reductions in P will not be as great as the reduction in soil erosion.

Andraski et al. (1985) have studied total P reductions associated with conservation tillage in the United States. In this study, fertilizer was subsurface banded at planting thus reducing the offsetting impacts of increased surface P concentration. With the elimination of the surface fertilizer factor it was found that no-till, chisel-till, and till-plant treatments on corn reduced total P losses by an average of 81, 70 and 59% respectively relative to conventional moldboard tillage. Even more significant was a reduction of bio-available P over the study period (4 yrs) with no-till, chisel till and till plant by 63, 58 and 27% respectively (Andraski et al. 1985). These findings, as well as those of Mueller et al. (1984) substantiate the value of conservation tillage for the reduction of P loading when surface fertilizer is controlled. Non-incorporation of fertilizer has been observed to produce nearly inverse results.

3.6.2 Phosphorus Enrichment Ratio

Phosphorus enrichment ratios (PER) have been calculated as the ratio of the P content of sediment (eroded soil) to that of the source soil. The phosphorus enrichment ratio depends primarily on the surface soil texture and the rate of soil loss. As noted earlier in this report, P is adsorbed most readily by the fines i.e. clay particles. As these fractions are also the most easily eroded, source areas exhibiting high clay content will display a high phosphorus enrichment ratio.

With regard to the relationship between erosion and enrichment, Massey and Jackson (1952) observed a reduction in the enrichment ratio as storm sediment concentrations and soil losses increased. Massey and Jackson (1952) used regression equations to estimate the effect of available P, surface runoff and soil loss on a phosphorus enrichment ratio. They found that PER increased as soil loss decreased and thus concluded that a practice which reduced sediment loss will not reduce nutrient losses proportionately. No measures are available to offset this relationship between soil loss and PER but, as noted earlier, reduction in soil loss is usually greater than the increase in the phosphorus enrichment ratio; thus a net reduction in total P loading will occur.

3.6.3 Phosphorus Concentration in Surface Soil

Adequate phosphorus fertility is essential for economically viable crop production. In recognition of the value of adequate P levels, most landowners in Southern Ontario apply fertilizer phosphorus to cropland as a routine part of their management system. PLUARG researchers (Miller and Spires 1978) have compared the average fertilizer P used on crops grown in several Southern Ontario watersheds to the average amount required for most economic production. It was found that, on average, fertilizer P additions exceeded the estimated requirements for all crops except hay-pasture. The application of excessive fertilizer P was predicted to increase the level of available P in the soil and the amount of P in runoff from fertilized fields (Miller and Spires 1978). Researchers further observed that the dissolved P concentration in runoff was increased to a greater extent than total P due to the solubility of recently applied fertilizer.

As noted in section 3.6.1., non-incorporation of fertilizer P or manure in a conservation tillage system may directly contribute to increased P yield from cropland. Baker and Laflen (1983) observed that the amount of nutrient in the soil profile directly influences the concentrations of nutrient in sediment and water. The amount present in the profile has been described as the sum of the amounts naturally present, the amount carried over from previous applications and the amount being added (Baker and Laflen 1983).

In addition to the amount of P present, its position in the soil profile strongly affects its concentration in runoff. As stated earlier, many researchers have noted a relationship between conservation tillage systems and the concentration of phosphorus at or near the soil surface. Alberts and Spomer (1985) and many others have discussed the stratification of nutrients in the soil profile under conservation tillage (no-till) systems. Unlike the moldboard plow which mixes nutrients and other chemicals throughout the plow layer, a no-till system accomplishes little if any vertical distribution of P through the soil profile.

In addition to fertilizer P, excessive phosphorus concentrations can be attributable to high rates of manure application. Like fertilizer, manure P can become serious when combined with no-till, or reduced tillage system. As reported earlier, Miller et al. (1982) found that dissolved P was high from fields having high available P or manure on the surface. These findings were provided in section 3.6. While the issue of manure-associated P in a conservation tillage system appears significant, a review of the literature did not produce any additional information regarding effective methods of manure management.

In the case of both fertilizer and manure P, land managers face difficult issues. Management based solely on water quality objectives suggests that nutrients should be incorporated into the soil to reduce chemical loss. However, in order to provide protection against erosion, many farmers are now seeking to maximize crop residue on the soil surface. Incorporation is not particularly acceptable from the standpoint of surface protection. Technologies such as shallow tillage or the use of "knives" to apply manure are being studied but Baker and Laflen (1983) suggest that their potential is limited. Soybean residue for example, is reduced by 61% with a single disking. Research is being conducted in the United States on the development of a "point injector applicator" that incorporates liquid manure without residue incorporation. Further research is reported on an implement designed to incorporate both nutrients and pesticides without incorporation of residue (Baker and Laflen 1983). Unfortunately, little published information is presently available on this research.

3.6.4 Sediment Delivery Ratio

The sediment delivery ratio is the major factor which, in conjunction with soil loss, determines P load. As indicated in section 3.5, the sediment delivery ratio is dependent on soil texture and topographic features. The proportion of the eroded soil that reaches surface water is greater in fine textured soils. Delivery is reduced by topographic features that reduce the rate of water flow or increase the time required for runoff to reach surface water courses. Dickinson and Pall (1982) and Rousseau (1985) note that distance from soil source to water course is a major determinant of delivery.

Dickinson and Pall (1982) and Baker and Laflen (1983) suggest that on medium textured rolling topography, increased surface roughness and infiltration caused through disruption of the soil surface by tillage and/or surface structure improvement will reduce delivery ratio. A search of the literature did not produce any research findings which document the extent of this reduction.

Buffer strips or other riparian vegetation that slows the movement of water has also been observed to be effective in reducing sediment and P delivery. Dickinson and Pall (1982) applied GAMES in a predictive mode and determined that such measures are effective in reducing sediment load on level areas. Unfortunately, P load can not be expected to decline by the same amount because of the influence of the phosphorus enrichment ratio, discussed earlier in this report.

With regard to P loading from cropland sources, PLUARG researchers (Miller et al. 1982, Wall et al. 1982) estimated that the areas of highest yield in southwestern Ontario, are the level, fine textured soils of Kent, Essex and Lambton counties. Fine textured clay soils have been found to remain in suspension for long periods of time. Ontario researchers (Dickinson and Pall 1982, Rousseau 1985) have thus observed that total volume of runoff rather than velocity are critical to P loading on level fine textured soils. Buffer strips along water courses have been suggested as possible remedial measures for the reduction of P loading from lowland areas. It has been shown, however, that sedimentation is seasonably variable with highest rates occurring during early spring (Dickinson and Pall 1982). During this period of the year there is no growth on the buffer strip and its effectiveness is therefore greatly reduced. In view of the foregoing, measures to reduce soil detachment and to improve subsurface drainage and infiltration would be more effective in reducing P load from these areas.

Methods for reducing soil detachment include improved structural stability through cover cropping and tillage. Each of these measures was discussed in section 2.4. Unfortunately, in southwestern Ontario, these measures are not easily applied to fine textured, level soils. The predominance of row cropping does not encourage the utilization of soil structure building crops, other than the combination of winter wheat and underseeded red clover. Difficulties relating to forages, particularly the lack of an off-farm market were also discussed in section 2.4. Little information is available in the literature regarding the effects of different perennial forages on the structure of fine textured soils. Most research, as reported earlier, has focussed on yield-related implications of various tillage and cropping methods for fine textured soils.

Subsurface drainage is an accepted practice on nearly level fine textured soils. Where soils are naturally poor in drainage, tile draining increases the volume of water flowing into the soil (infiltration) and therefore reduces the volume of water flowing over the surface of the soil (runoff). In areas where the volume of surface runoff is a major problem, tile drainage could have significant impact in reducing that volume. On these areas, the objective of farmers is to remove the surface water quickly; hence surface drains are used extensively.

For tile drainage to be effective, the water must be able to flow into the tile drain at a reasonable rate. The rate of conductance of the water flow through the soil depends to a large extent on soil structure and occurrence of large connected pores. Thus management can influence the efficiency of tile systems by influencing surface and subsurface soil structure. Subsurface structure problems can possibly be by-passed in relatively level topography by using smaller diameter, near-surface tile systems. Near-surface tile systems have not been adequately field tested. In soils with rolling topography, where the velocity of surface water flow is a major cause of soil erosion, the significance of tile drainage as a remedial measure will be greatly reduced.

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